REGIONAL ANALYSIS OF LOW FLOW CHARACTERISTICS

CENTRAL AND SOUTHEASTERN REGIONS

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March, 1990

Report prepared for:

Ontario Ministry of Environment and Energy

DISCLAIMER

7268
November 5, 1991

Dr. L. Logan
Coordinator, Hydrology Network
Ministry of the Environment
River Systems Unit
7th Floor
1 St. Clair Avenue West
Toronto, Ontario
M4V 1K6

Dear Dr. Logan:

Re: Regional Analysis of Low Flow Characteristics
Central and Southeastern Region

Please find enclosed our final report concerning the above noted study which incorporates your review and comments.

Overall, the results of the various methods for regionalizing low flows show promise in that the estimating error which has been achieved appears to be as good or better than that reported for other similar investigations in the literature.

Thank you for the opportunity to undertake this most interesting investigation.

Yours very truly,

CUMMING COCKBURN LIMITED

H. S. Belore, P. Eng.
Director of Water Resources

D. A. Ashfield, P. Eng.
Project Manager

HSB:ty
Encl.

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd)

LIST OF APPENDICES

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

SYMBOLS	DEFINITION
ACLS, FALAKE	• Area controlled by lakes and swamps
ARMAY	• Adjusted Simulated in days low flows with y years of recurrence interval. (reflows have been changed to zero).
b	• Parameter estimates obtained from the use of Multivariate regression procedures
BFI	• Base flow index
CF	• Correction factor
CO	• Watershed perimeter
DA	• Drainage area
EVA	• Mean annual evaporation
GW	• Maximum groundwater fluctuations
GLS	• Generalized least squares
GRADMEN	• Slope of the n day average low flow
H	• Watershed Relief
INF	• Infiltration, recharge or deep percolation defined by MAP-MAR-EVA
k	• Hydraulic conductivity
K_b	• Dimensionless base flow recession constant
LAT	• Latitude
LNTH	• Stream length
Ln	• Natural logarithm
Log	• Logarithm to the base 10
LONG	• Longitude
MAM (10)	• Mean annual minimum 10-day low flow

SYMBOLS	DEFINITION
MAP, SAAR	• Mean annual precipitation
MAR	• Mean annual runoff
MAS	• Mean annual snowfall
MED (10)	• Median 10 day low flow value
nQy	• Average consecutive n days low flow with y years of recurrence interval
OLS	• Ordinary least squares
P	• Slope of recurrence interval graph
P1	• $(LNTH/\sqrt{SLP})^{1/2}$
P2	• $(BFI/(LNTH/\sqrt{SLP}))^{1/2}$
Q_o	• Observed flow
Q_m	• Mean observed flow
Q_s	• Simulated or predicted flow
Q_t	• Runoff at any time, t
R_nQ_y	• Simulated n days low flow with y years of recurrence interval
R_{10}	• 10 Year Maximum rainless days
q	• Estimated flow
qb	• Base flow
Qi	• Average minimum daily flow
$Q_{95}(n)$	• Average flow exceeded by 95% of n day average discharge
qr	• Regressed estimate
Qs	• Average minimum summer flow
$7Q_{10}$	• Consecutive average 7 day flow recurring every 10 years
SF1	• Shape factor 1 defined by $DA/LNTH^2$

SYMBOLS	DEFINITION
SF2	• Shape factor 2 defined by DA/LNTH
SF3	• Shape factor 3 defined by DA*SLP*LNTH/2
SI	• Soil index
SLP	• Stream channel slope
t	• Time
T_{10}	• 7 Day 10 year maximum temperature
Xi	• Drainage basin and climatic characteristics
YRS	• Number of years of record

1.0 INTRODUCTION

1.1 General

The knowledge of the hydrologic conditions which exist during low flow conditions can be of primary importance for some watercourses. For example, when analysing water quality conditions, the low flow characteristics of a watercourse are a major concern to both the landowner and the Ontario Ministry of the Environment. Other uses of low flow information may include the following:

1) Instream pollutant analyses (point and non-point sources)
ii) Reservoir design (low flow augmentation)
iii) Environmental appraisals
iv) Feasibility of small hydro developments
v) Water supply and evaluation for water taking permits
vi) Base flow/groundwater recharge and/or contamination analysis
vii) Stream fisheries assessments
viii) Analyse effects of changes in watershed on low flows (e.g. deforestation, urbanization)
ix) Agricultural

The identification of low flow characteristics within a watercourse is most easily accomplished using continuous hydrometric data recorded for the stream.

A primary source of information describing drought conditions is the "Low Flow Characteristics" maps which were recently updated by Cumming Cockburn Limited for the Ministry of the Environment. This update also included individual reports on the regions listing gauging station data, results of non-parametric testing of low flow data, tables and graphs of low flow values and characteristics for both extreme value and flow duration analysis. A large data base exists with all of this data. However, the effectiveness of utilizing single station analyses is limited since a hydrometric recording gauge may not be located in the vicinity of the study site.

Useful techniques do not presently exist for transferring this information to ungauged sites. The use of appropriate techniques (e.g. station proration by unit flows, area, etc.) are limited by several assumptions, including:

- ignoring the effects of regulation or upstream storage (lakes, swamps, etc.)
- assuming the watersheds are homogeneous (i.e. physiographic characteristics are ignored)
- assuming the climatic regions are homogeneous.

Cumming Cockburn Limited recently completed a preliminary research program which describes the initial stages of development of techniques to produce low flow estimates for ungauged sites for the Southwestern and West Central regions in Ontario.

The study included a literature review of similar relevant investigations. In all, five methods for estimating low flows were examined.

The recent investigations have led to the identification of several areas of research to be further developed for estimating low flows for ungauged watersheds. The present study was undertaken to confirm the applicability of regional transfer to modify and enhance the applicability of available methods, and to develop further insight into predicting low flow values at ungauged locations. The test areas selected were the Central and Southeastern regions of the Province of Ontario (see Figure 1.1).

1.2 Study Objectives

The main objective was to further refine techniques for providing estimates of low flow characteristics for ungauged streams based on the physical parameters of the watershed and appropriate meteorological variables.

It is expected that the technique could then be further developed and adapted in order to provide estimates of low flows for ungauged watersheds at other locations in the Province.

The following points summarize the focus of this investigation:

B. Central Region
C. Southeastern Region

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Consulting Engineers and Planners

STUDY LOCATION

FIGURE - 1·1

1) To test the available methodologies for predicting low flows in the Central and Southeastern regions. To identify suitable techniques for application and required research/refinements (e.g. by comparison of regression and mapping techniques)
2) To develop an appropriate data base including additional parameters such as evaporation, groundwater fluctuations (well records), etc.

2.0 LITERATURE REVIEW

2.1 General

This updated literature review augments the previous search (Cumming Cockburn Limited, March 1990) with recently published information on low flow characteristics. A summary of the relevant results of the review of the various investigations is given in Table 2.1 and discussed in the Summary section 2.2.

The following sections summarize highlights from selected references. The reader should refer to the original reference before attempting to apply specific equations since the units and parameter definitions vary from report to report. The intent here is only to identify important parameters for further consideration in this investigation.

Probability Distribution of Low Flows (Matalas, N.C., 1963)

This study examined the fit of four probability distributions using both the method of maximum likelihood and moments. The Gumbel and Pearson Type III distributions fitted the data equally well and were more representative of the probability distribution than the 3 Parameter Log Normal or Pearson Type V distributions. Goodness of fit was based on observed minimum flow, the lower limits of the four probability distributions and the relation between skewness and kurtosis of the low flow data. It was recommended that future statistical studies of low flows should use the method of maximum likelihood estimates of parameters rather than moment estimates.

Modelling of Low Flow Frequency Distributions and Parameter Estimation (Condie, R. and G. Nix, 1974)

The fit of four theoretical frequency distributions was examined in this study. The Gumbel III distribution was selected as the best fit for extreme value analysis of low flows since it produced 33 acceptable fits out of a possible 38 for the Canadian rivers used in this study. A program FLOINT was written to handle low flow values of zero using a joint/conditional probability function. A discussion of the lower boundary limit being between zero and the lowest recorded flow concluded that the lower boundary can be less than zero since it represents the curve of the line and not the actual flow.

Hydrology of 7 Day 10 Year Low Flows (Singh, K.P. and J.B. Stahl, 1974)

This paper discusses three pertinent factors in the broad headings of; 1) basin factors; 2) climatic factors, and 3) sociological factors. The main discussion is based upon man's influence and requirement for low flow. It is suggested that basin input to a $7Q_{10}$ low flow study includes information on daily streamflows, soil and stream characteristics, physiographic and hydrologic diversion boundaries, municipal and industrial water use and/or man-made lakes and flow regulation. Again, it is stressed in the conclusions that the magnitude of the drainage area is the most important factor affecting the natural $7Q_{10}$ of hydrologically similar basins.

Determining Streamflows from Geomorphic Parameters (Osborn, J.F., 1974)

Osborn examined the many interconnected relationships of geomorphic parameters of basins to flows. An example of the basin characteristics interrelationship is that LNTH = 1.4 $(DA)^{0.6}$, where LNTH is stream length and DA is area. It is noted that the coefficient and power values vary for different geographic areas.

The equations for estimating average annual flow (QAA) took the form QAA = C" $(P)^a$ $(DA)^b$ where P is average annual precipitation and the coefficient and powers are determined from regional regressions.

It is noted that minimum or low flows tend to be more sensitive to a larger number of parameters than flood flows. Assuming linear flow-frequency relationships, a parameter Q7LIP was developed to relate the relative maximum size of low flow in one stream to another. This value was then regressed with basin parameters to establish $7Q_2$.

$$7Q_2 = B\left[\frac{DA \cdot H)^{0.5}\ Q7L1P}{300(P)}\right]^m$$

where B is a coefficient

H is basin relief

P is slope of recurrence interval graph

The P parameter also represents a measure of the stability of the natural basin storage from which the low flow is derived. The value $7Q_2$ was then used as an index flow to predict other recurrence interval flows as:

$$7Q_{20} = \frac{P(7Q_2)}{C}$$

where P is slope and C is a coefficient. For example,
$\log 7Q_{20} = \log (P(7Q_2)) - \log C'$

Relationships were also found between peak flows and low flows. It was determined that if basins were of the same average annual runoff then you assume C′ is essentially the same and examine the peak flows, if they are different, then low flows must be different and the basins are not hydrologically similar.

Combining Estimates of Low Flow Characteristics of Streams in Massachusetts and Rhode Island (Tasker, G.D., 1975)

This report presents a statistical analysis of baseflow measurements and a discussion of the accuracy produced by varying the sample size. It was concluded that empirically estimated values of variance of the estimated $7Q_{10}$ low flow from its true value indicate that more than six or eight baseflow measurements add little to the confidence with which such an estimate is made. As well, the number of baseflow measurements needed to meet a specific accuracy of low flow characteristics can be significantly reduced by considering prior knowledge of the low flow characteristics quantitatively. The formula is:

$$q = \frac{q_r + (Sr^2/Sb^2)\, q_b}{1 + (Sr^2/Sb^2)}$$

where

q	is logarithm of estimated low flow characteristics
q_r	is log Q_r flow estimated by regression of basin parameters
q_b	is log Q_b flow estimated by regression of base flow measurements
Sb^2 & Sr^2	are variances in square log units of estimates from true value of low flow characteristics

An Infiltration Index Useful in Estimating Low Flow Characteristics of Drainage Basins (Armbruster, J.T., 1976a)

This investigation concluded that the basin geology was an overriding factor in describing low flow characteristics. Using an SCS soil type based infiltration index, the author of this study was able to improve standard errors in existing prediction equations. The soil index was determined by percentage of basin of soil type A, B, C or D and applying a weighting of 10, 5, 1, 1 respectively and summing for the entire basin. The drainage area and a precipitation index were also found to be significant factors in estimating low flows. The final equation takes the following form:

$$\log 7Q_{10} = -4.658 + 1.068 \log DA + 2.183 \log MAP + .218\ SI$$

where SI is Soil Index

Technical Manual for Estimating Low Flow Frequency Characteristics of Streams in the Susquehanna River Basin (Armbruster, J.T., 1976b)

This technical report adopted the infiltration index described in the earlier reference by Armbruster which examined step-by-step procedures for low flow frequency characteristics. In addition, distinctions were made between large and small drainage basins. Large basins have drainage areas of larger than 5,120 km^2 (2000 mi^2). The parameters used in the regressions were; drainage area, mean annual precipitation, basin surface storage, index of relative infiltration. As well, an index coefficient of the 1 day flow to the 3 day flow of .93 was determined. For large basins, a graph of correction factors for channel length was produced and applied to the regression equation as:

$$\log (7Q_{20}) = -2.029 + 1.052 \log DA + .753 \log (MAP) + CF$$

where CF is the correction factor from the graph.

Estimates of Low Flows Using Watershed Climatic Parameters (Boyer, P.G. and M. Chang, 1977)

A regional analysis was undertaken for 12 unregulated mountainous watersheds with drainage areas ranging from 164 km^2 to 2345 km^2 (64-916 mi^2) located in West Virginia. There was considerable effort put forward in developing physical watershed parameters for which the evaporative power and drought potential were related logically. Eighteen watershed parameters were tested; drainage area, length of perimeter, mean elevation, mean latitude, maximum relief, relief ratio, basin slope, form factor, main channel slope, main channel length, drainage density, stream frequency, stream order, average angle of tributaries, aspect, length-width ratio, coefficient of compactness and percent of forest cover. Climatic parameters used for analysis were 7 day mean maximum temperature and maximum consecutive days without precipitation for seasonal periods of August to October.

The final model used 3 watershed and 2 climatic parameters, namely; watershed perimeter (CO), the main channel length in miles (LEN), the Watershed Form Factor (WF) (area/maximum watershed length^2). The 7 day 10 year maximum temperature (T_{10}), a function of mean elevation and latitude, and the September 10 year maximum consecutive rainless days (R_{10}), and finally, a function of watershed mean elevation. A prediction equation was developed for the 1:10 year 7 day low flow with a standard error of estimate of about 30% of the observed mean:

$$\ln (7Q_{10}) = 37.0469 + 0.03886 (CO) - 0.0401 (LNTH) - 3.6743 (WF) - .5771 T_{10} + 1.1665 R_{10}$$

It was concluded that use of climatic parameters which index drought conditions can improve low flow estimates, and that meaningful low flow estimates can be obtained from climatic and watershed parameters or watershed parameters alone in a mountainous humid region.

Analysis of Low Stream Flows on Cape Breton Island, Nova Scotia (Environment Canada, 1978)

This investigation included frequency analysis using Gumbel III, for 1, 3, 7, 10, 30 day low flow durations based on 11 hydrometric stations with drainage areas ranging from 216 km^2

to 3.6 km^2 (142 - 2.4 mi^2). Stations with periods of record from 10 to 59 years were used and those with man-made regulation were deleted.

It was determined that extreme low flow estimates for the short-term hydrometric stations may be high. Seasonal analysis found higher low flows for the summer period. It was suggested that this was due to the climatic and physical location of the stations, and it was noted that evaporative power may also be important. As well, a physiological data base was prepared for a future regression study of 13 parameters relating to the stations examined (see Table 2.1).

<u>Journal of the Hydraulic Division - Characteristics of Low Flows</u> (Task Committee, Surface Water Hydrology, 1980)

This paper summarizes the findings of a U.S. committee regarding the types of low flow information needed, various low flow characteristics and their accuracy, and suggests further analysis and data collection needs. The main topics were discussed according to gauged sites and ungauged sites.

a) Gauged Site

The most widely-used index of low flow in the U.S. is the 7 day 10 year low flow ($7Q_{10}$). However, it was also found that other durations of from 1-273 days have been based on data records of 15-20 years or more.

b) Ungauged Sites

It was found that low flow characteristics depend largely on the geology of the basin and on losses from evapotranspiration. For example, the incorporation of basin rock type into regional analysis of low flows increased prediction accuracy for equations developed in Virginia. A regional low flow forecasting model developed (by Wright, 1970) for southeast England relates lowest mean flow for the forecast year to; drainage area, mean annual runoff, geology index, mean summer catchment rainfall in the same year as forecast and mean winter catchment rainfall (October-March) preceding forecast low flow.

Low Flow Studies (Institute of Hydrology, 1980)

The Institute of Hydrology (U.K.) analysed low flows using regression techniques. An innovative feature was the development of a geologic index called the baseflow index. This index can be determined from streamflow measurements (for equation see Condie, 1986). In ungauged areas, comparative areal methods can be used to estimate the BFI or it can be estimated from underlying geology.

Low flow duration curves were regressed from basin parameters. Then a comparative analysis of the change of slope for different n-day durations allowed for a prediction of any n-day low flow. In the study, much work was done to provide non-dimensional graphs and to linearize them for simplifying the estimation procedures.

The regional equations take the form:

$$Q_{95}\,(10) = C_1\,\mathrm{BFI} + C_2\,\mathrm{MAP} - C_3$$

and $$Q_{95}\,(10) = C_4\,\mathrm{BFI} + C_5\,\mathrm{LNTH} - C_6$$

where MAP = mean annual precipitation
LNTH = stream length for region five.

As well, the slope is regressed from parameters as:

$$\log_{10}\mathrm{GRADMEN}\,Q_{95} = C_7\,\mathrm{MAP} - C_8\,Q_{95}(10) - C_9$$

These two regression equations were then used to estimate Q_{95} (n) for any n-day duration by the formula:

$$Q_{95}\,(n) = Q_{95}\,(10)\,[1 + (D\text{-}10)\,\mathrm{GRADMEN}\,Q_{95}]$$

Similar relationships were developed for mean annual minimum 10-day low flow MAM (10). Included in the report describing this five year study is a fairly extensive literature review which is paraphrased below.

<u>Review of the Institute of Hydrology Background Review</u> (Institute of Hydrology, 1980)

"Many examples worldwide employ catchment characteristics indexing catchment size, shape and climate and most refer to the additional need to consider the geology of the catchment in order to explain more of the variability of low flows. Wright (1970) presents a prediction equation for the lowest flow in a year using catchment slope and area as independent variables. Riggs (1973), Wesche et al (1973), and Skelton (1974), make use of the cross-sectional properties of streams to correlate low flows with neighbouring gauged catchment data. For the United Kingdom, general information on behaviour of British rivers is given by Ward (1968) and also Rodda (1976). The interaction between surface and groundwater for major aquifers is discussed in Ineson et al (1965). Much design work has been based on the lowest recorded flow. Flow duration curves and their application in the U.K. are given in Hoyle (1963). They are discussed by Boulton (1965) where the concept of a Minimum Acceptable Flow is described and the factors likely to enter into its calculations are considered."

<u>Flood Prone Area and Low Flow Analysis Study in the Kawartha Region</u> (MacLaren Plansearch, 1981)

This study developed a regression equation for predicting low flow estimates in the Kawarthas region. The regression equations took the form:

$$\frac{\overline{Qi}}{DA} = 1.64 \times 10^{-3}\ SI^{3.171}\ ALS^{-0.116}$$

$$\frac{\overline{Qs}}{DA} = 6.90 \times 10^{-4}\ SI^{1.365}\ ALS^{-0.102}$$

where $\overline{Qi}$ = average minimum daily flow

$\overline{Qs}$ = average minimum summer flow

DA = drainage area

SI = index of average soil moisture holding capacity

ALS = % area covered by swamp or wetland

Application of Statistical Low Flow Analysis as a Basis for Water Quality Planning (Rubach, H., 1982)

Two practical examples for applications of statistical low flow analysis as related to water quality management were discussed. In the first example, water quality parameters were described as a function of runoff of defined frequency. This was used as information to determine the necessary amount of low flow augmentation. In the second example, the necessary size of storage volumes desired for low flow augmentation was estimated. The storage volumes depended on the desired minimal runoff value, the frequency and the duration of the augmentation process. To generate information about mean low flows for defined durations and frequencies, a duration-runoff-frequency function was determined. On the basis of daily runoff values, the mean low flow was calculated for a set of different durations of low flow periods. For each duration step, the yearly lowest value of mean low flow in the period of this duration was used as an element of a series of extreme values. A frequency distribution was fitted to this empirical series of extreme values to extrapolate low flows of defined frequencies.

Low Flow Frequency Analysis (Program LOFLOW) (Condie, R. and L. Cheng, 1983)

The Gumbel Type III distribution is discussed as well as conceptual problems found from the Condie, Nix 1975 study. It was found that the Gumbel III distribution becomes unstable if the sample has a skewness of less than -1.08. This study concluded that the Gumbel III distribution should be used as the basic method for low flow frequency analysis. As an alternative for samples with large negative skewness, it was suggested that a 3-parameter log normal distribution should be used.

The only criteria of successful fit to the Gumbel III is that the lower boundary parameter should not be larger than the smallest member of the sample. Parameter estimation should proceed in the order of; maximum likelihood, smallest observed drought and by moments. The program LOFLOW was written to analyse samples of low flows taking these concerns into account.

Computation of the Base Flow Index program (BFINDEX) (Swan, P. and R. Condie, 1983)

It was determined that low flows are very dependent on catchment geology, and the Base Flow Index was suggested as a practical technique to provide an index of this parameter. A program was written to calculate a base flow index (BFI) as:

$$BFI = \frac{\text{total volume of base flow/yr}}{\text{total volume of runoff/yr}}$$

The required data was obtained from records published by the Water Survey of Canada, and averaged BFI values were computed over a period of several years.

The main problem with this technique was determined to be the requirement for discharge measurements. However, it was pointed out that the BFI parameter was found to be fairly stable over both wet and dry years and, it was, therefore, concluded that it could be estimated from as little as one to two years of discharge measurements.

Effects of Man on Low Flows (Riggs, H.C., 1984)

This investigation examined the climatic, geologic and topographic influences on low flow characteristics in view of man's influence. Man-made changes that affect low flows were identified as changes in vegetation, drainage practices, diversions, return flows, groundwater pumping, sewage treatment plants and other effluent discharge.

It was pointed out that the aquifer characteristics are also important to low flows. It was postulated that evapotranspiration and changes to ground cover can likely be related to low flow increases. Urbanization is not a significant factor since pluses (i.e. sewer leakage) and minuses (i.e. reduced infiltration) tended to even out. Reservoir regulation usually increases low flows due to minimum outflow requirements. Diversions are highly basin dependent and are difficult to assess.

It was noted that swamps apparently had very small low flows in extreme drought cases. Therefore, it was postulated that changes to swamps (e.g. by infilling, etc.) might not have a significant impact on downstream low flow characteristics. Pumping can have a large effect depending on duration location and basin geology. The three main parameters for low flow

are related by; climate providing input and output, geology and topography influencing infiltration to aquifers, and then geologic parameters affecting transport to streams.

Man's influence on precipitation, temperature and irrigation are not likely to affect low flows while changing vegetation cover (evapotranspiration), regulation and diversion are likely to have the most evident effects on low flow.

Hydrologic Design Methodologies for Small Scale Hydro at Ungauged Sites (Acres, 1985)

This study developed a regression relationship between basin physiographic parameters and "turbinable flow" which was related to exceedance curves. Exceedance curves were non-dimensionalized by dividing flow values by the mean annual flow. For ungauged sites, a regression equation provided estimates of mean annual flow from values of MAR and area.

$$MAF = 0.0000369\ MAR \cdot DA$$

This was then related to a regional indexed curve to determine values of exceedance by examining the regional mean annual flow to the sight mean annual flow.

As well, two other methods were compared, proration and ARMA (Autoregressive Moving Average Methodology). It was determined that proration provided the best practical method for determining discharge. The proration formula took the form:

$$Q_{ijk} = QI_{ijk}\ (DA\ MAR)\ /\ (DAI\ MARI)$$

where i = year, j = month, k = day

The ARMA method was used to synthesize daily and monthly flows from required parameters within the basin over a time series.

Median Drought Flows at Ungauged Sites in Southern Ontario (Pilon, P. and R. Condie, 1986)

A methodology was suggested and explored for predicting median drought flows at ungauged sites in Southern Ontario. Minimum average flows for durations of 3, 10, 14, 21 and 28 consecutive days were determined each year in the time period June 1 to May 31 for

74 stations in Southern Ontario. A regression equation was developed for predicting the median 10 day low flow using drainage area (DA), mean annual precipitation (MAP), and base flow index (BFI). The precipitation parameter was not significant and, therefore, not included in the equation. The standard error of the low flows was found to be 37% and the equation was in the form:

$$MED(10) = 0.000075\ DA + 1.515\ BFI - 0.356$$

The median 10 day low flow was then used to produce a slope relationship to relate other low flow durations to the MED(10) value. This equation is expressed as:

$$GRADMEN = 2.632\ MED(10) + 0.46399$$

Where GRADMEN is the slope of the median flow duration relationship.

A problem noted by the authors is the determination of BFI for ungauged sites. The parameter is used as an index of catchment geology.

Drought Flows and Receiving Water Assessment (Logan, L., 1986)

This study examined low flows in an environmental context with respect to waste water and failures to satisfy water quality requirements. Low flow design estimates for Central - Southeastern Ontario were reported to be:

	Central ($m^3/s/km^2$)		Southeastern $m^3/s/km^2$		
$7Q_{20}$	1.0	-	0.4	)	
$7Q_{10}$	1.1	-	0.6	)	$\pm .3\ m^3/s/km^2$
$7Q_2$	1.8	-	1.7	)	

The MOE guideline on drought flow design is $7Q_{20}$. This implies that lower low flows will cause water quality violation in BOD and other wastes.

Approach for Frequency Analysis of Multiyear Drought Durations (Lee, K.S., J. Sadeghipour, and J.A. Dracup, 1986)

An approach for frequency analysis of multiyear drought durations was presented. The problem of sample size is discussed with a technique for smoothing frequency-curve

irregularities of drought durations. Piecewise linear regressions for the linearized termination probability curve define the parameters of the logistic model. The model then can be used to determine the return periods of multilinear droughts. This report, although interesting, is not directly applicable to the present investigations.

Regional Flood Frequency Analysis for Ontario Streams, Volume 2, Multiple Regression Method (Moin, S.M.A., and M.A. Shaw, 1986

This report primarily concerns prediction of flood peaks although it includes a discussion of the Base Flow Index which may be relevant for the present investigations. The BFI was calculated and mapped for 2 flood regions identified in the Province.

The regression equations with BFI for predicting flood flows provided predictions superior to those derived using the secondary regression equations without the BFI parameter. The latter was found to be second only to drainage area as a significant parameter in describing variance of flood flows.

The BFI was found to be extremely sensitive to basin storage conditions and, therefore, could not be used in the primary regression equations for the northern region due to the large number of lakes and swamps.

Correlations with SCS soil groups indicated that BFI could be approximated as follows:

Soil Group A	> 0.60±
Soil Group B	0.45±
Soil Group C	0.30±
Soil Group D	< 0.25±

Low Flow Studies in Scotland (Institute of Hydrology and Department of the Environment, 1986)

The report described a method of estimating monthly and seasonal flow duration curves at sites where little or no flow data are available. The method was developed to estimate the 95 percentile, 10 day flow from the annual flow duration curve, Q_{95} (10), 10 day average flow

Low Flow Studies in Scotland (Institute of Hydrology and Department of the Environment, 1986)

The report described a method of estimating monthly and seasonal flow duration curves at sites where little or no flow data are available. The method was developed to estimate the 95 percentile, 10 day flow from the annual flow duration curve, Q_{95} (10), 10 day average flow exceeded by 95% of 10 day average discharge, Q_{95} (10) was estimated in units of percentage of average flow in m^3/s by using regression equations developed for different regions using the Base Flow Index (BFI) and standard period (1941-70) annual average rainfall (SAAR) or defined as MAP (Mean Annual Precipitation) in the present study. The generalized form of the regression equation was:

$$\sqrt{Q95(10)} = a_0 + a_1 \sqrt{BFI} + a_2 \sqrt{MAP}$$

For Flow estimation at the ungauged sites, regression equations were revised for each of these regions for estimating Q95 (10) and MAM (10) (mean annual 10 day minimum) from the Base Flow Index (BFI), Standard Annual Average Rainfall (MAP), and Proportion of Catchment Covered by a Lake or Reservoir (FALAKE) or ACLS (Area controlled by lakes and swamps as defined in the present study). The generalized low flow regression equations are given below:

$$\sqrt{Q95(10)} = a_0 + a_1 \sqrt{BFI} + a_2 \sqrt{MAP} - a_3 \sqrt{ACLS}$$

$$\sqrt{MAM(10)} = a_0 + a_1 \sqrt{BFI} - a_2 \sqrt{ACLS}$$

The negative regression coefficient of ACLS does not imply that catchments with lakes have lower low flows than those without. This apparent paradox is resolved by recalling that the attenuating effect of a lake on the downstream hydrograph will greatly increase the BFI. This results in higher BFI in catchments with lakes for a given Q95(10) than in lake-free catchments and so this increased BFI is compensated in the equation by a negative coefficient of ACLS. The same phenomenon was noted in the equation developed for predicting MAM(10). The other notable feature of the equations is that SAAR is a useful explanatory variable for Q95(10) but not for MAM(10). This was attributed to the finding that Q95(10) was higher in wet than in dry areas having the same BFI but that MAM(10) was independent of rainfall in most regions.

<u>A Comparison of Methods for Estimating Low Flow Characteristics of Streams</u> (Tasker, G.D., 1987)

Four methods for estimating the 7 day, 10 year and 7 day, 20 year low flows for streams were compared by the bootstrap method (Log-Pearson III, Weibull, Box-Cox and Log-Boughton). The bootstrap method is a Monte Carlo technique in which random samples are drawn from an unspecified sampling distribution defined from observed data. The non-parametric nature of the bootstrap makes it suitable for comparing methods based on a flow series for which the true distribution is unknown. It was found that when all the data were used, all four methods gave reasonably close estimates. However, in general, the methods based on hypothetical distributions (the LP III and Weibull methods) performed better in terms of mean square error than did the Box-Cox transform method or the Log-Boughton method which is based upon a fit of plotting positions. The LP III method performed marginally better than the Weibull except for very short record lengths where both methods were found to be about equal. The authors concluded that the results reported did not extend over the entire range of low flows and did not imply that one particular distribution was better than another in describing the distribution of low flows.

<u>Low Flow Characteristics in Ontario</u> (Cumming Cockburn Limited, 1989)

The study was undertaken to update the statistical low flow analyses for all the five administrative regions and to produce extreme value analyses for suitable stream gauging locations (1, 3, 7, 15, 30 day durations) with record lengths greater than 10 years. The minimum annual consecutive 7 day average low flow was determined for each year and the corresponding set of consecutive 7 day average low flows represented an extreme value series to which a theoretical extreme value distribution was fit. It was noted that previous investigations generally utilized the Gumbel III distribution. In addition, statistical characteristics of average low flow values for all of Ontario were compared to those for each region. It was noted that a higher than expected number of station's data illustrate some trend and persistence.

Environmental Ontario Research Project : Assessment of the Biologically Based Low Flow Analyses Technique (Cumming Cockburn Limited, 1989)

This study analysed and compared the existing hydrologic methodology for defining low flows (extreme value analysis) to a biologically based methodology developed by the U.S. EPA (Environmental Protection Agency). The report concluded that the biological low flow model could successfully be applied to river systems in Ontario. The $7Q_{20}$ hydrologically defined low flow is similar to the chronic design flow in terms of flow magnitude and the expected number of excursions from water quality objectives. The report recommended that the MOE should continue use of the $7Q_{20}$ as the design low flows for the Province of Ontario.

Generalized Low Flow Frequency Relationships for Ungauged Sites in Massachusetts (Vogel, R.M. and C.N. Kroll, 1990)

Generalized regional regression equations for estimating the n-day, y-year low flow discharge, nQy, at ungauged sites in Massachusetts were developed for n = 3, 7, 14 and 30 days. A 2-parameter log normal distribution was fit to sequences of annual minimum n-day low flows and the estimated parameters of the log normal distribution were then related to two drainage basin characteristics; drainage area and relief (for 23 sites with natural flow). It was pointed out that many previous investigations had developed regional models for estimating low flow statistics at ungauged sites from readily available geomorphic, geologic, climatic and topographic characteristics (e.g. Thomas and Benson, 1990). Usually these models take the form:

$$nQy = b_o X_1^{b_1} X_2^{b_2} X_3^{b_3}$$

where nQy is obtained from gauged streamflow records, the X_i are easily measured drainage basin and climatic characteristics, and the b_i are parameter estimates obtained from the use of multivariate regression procedures. Vogel, et al (1989) presented a regional low flow model that describes the time response of runoff from a watershed during dry periods. Describing the watershed as a system of linearized Dupuit-Boussinesg aquifers, they found that watershed runoff (Q) at time t_i after the hydrograph peak may be described by the

$$Q_t = 4k\ (DA)\ (Hd)^2\ K_b^t$$

where k is the hydraulic conductivity of the aquifer, DA is drainage area, H is watershed relief, d is drainage density, K_b is the dimensionless baseflow recession constant and t is time. The product SLP is an approximation to the average basin slope. The basin relief, H, is defined as the difference in elevation between the basin summit and the basin outlet where the basin summit elevation is the average of the highest peak and the two adjacent peaks on either side of it. Unfortunately, accurate estimates of k and k_b were found to be difficult to obtain at ungauged sites; hence those characteristics were ignored. The inclusion of drainage density, d, did not result in improvements of estimates of low flow characteristics at ungauged sites, hence that basin characteristic was ignored, hence this study (Vogel and Knoll, 1990), assumed that low flows could be characterized by watershed area and basin relief alone. The low flow predictions from this model were comparable with previous regional low flow investigations in terms of average prediction errors. It was emphasized that further reductions in the prediction errors associated with such regional low flow models will likely result from the inclusion of additional watershed characteristics such as basin hydraulic conductivity, average basin slope and the baseflow recession constant. The study also compared the use of generalized least squares and (OLS) regression procedures. The study concluded that the GLS and OLS regression procedures led to almost identical regional regression model parameter estimates although GLS procedures led to only marginal gains in the prediction errors associated with low flow regional regression equations.

Regional Analysis of Low Flow Characteristics (Southwestern and West Central Regions) (Cumming Cockburn Limited, 1990)

The study developed regional regression equations based on Drainage Area (DA), Base Flow Index (BFI), stream length (LNTH), other parameters, for example, Mean Annual Runoff (MAR) and Mean Annual Snowfall (MAS) were also examined. The generalized regression equation developed was of the following form:

$$nQy = a_0 + a_1\ DA^3 + a_2\ BFI^2 + a_3\ LNTH^2$$

where nQy is the n-day average low flow occurring once in y years.

The study concluded that the regression utilizing Drainage Area, Base Flow Index and Stream Length as independent parameters provide reasonable estimates of low flow values. It was also found that the equations for estimating low flows were sensitive to variations in values of Base Flow Index (BFI) and Length (LNTH). It was, therefore, concluded that care should be taken in estimating these parameters for ungauged watersheds. For estimation of the BFI, it was concluded that available maps of BFI isolines could be used or short term monitoring (2 years) could provide good estimates. Finally, it was also concluded that the Index or graphical and regression methods provided superior estimates of low flows compared to those obtained solely from station proration of unit area low flows from gauged sites.

2.2 Summary of Literature Review

In summary, it was found that many investigators have analysed low flow characteristics over durations from 1 to 273 days in length, for return periods of 1 to 100 years. In general, it has been determined that the Gumbel III and Log-Pearson III distributions best fit the samples of low flow data for gauged streams (Tasker, 1987, Condie and Nix, 1975, Matalas, 1965 and Table 2.1). Several investigations considered techniques for predicting selected low flow characteristics while very few investigations have considered techniques for developing regionalized flow duration curves.

Parameters found to be significant in regression equations generally tended to be drainage area, base flow index, mean annual precipitation, area controlled by lakes and swamps, watershed relief, stream length, mean annual snowfall, mean annual evaporation, groundwater fluctuations, mean annual runoff and soil index. However, some parameters that were not found to be highly correlated in one region were found to be important in other regions (Institute of Hydrology, 1980).

With reference to the available literature, it was decided to include the following parameters in development of the physiographic, meteorologic and hydrometric data base; drainage area (DA), mean annual snowfall (MAS), mean annual precipitation (MAP), mean annual runoff (MAR), mean annual evaporation (EVA), area controlled by lakes and swamps (ACLS), slope (SLP), stream length (LNTH), Base Flow Index (BFI) and maximum groundwater fluctuations (GW).

TABLE 2.1

SUMMARY OF LITERATURE REVIEW

Study	No. of Stations	Distri-bution	Method	Parameters Examined	General Form of Equations
Wright, 1970			Regression	DA,BS,MAP	MAM = f(DA, BS) MAM = f(DA, BS, MAP)
Osborn, 1974	20		Index Regression	Q7L1P,P,DA,H,CL,DD	log $7Q_2$ = f(DA, H, Q7LIP, P)
Taster, 1975		LN III	Regression		$7Q_{10}$ = f(DA, MAP, T)
Armbruster, 1976a Armbruster, 1976b	104		Regression	DA,CS,BL,EL,FC,MAP, ACLS,MAS,SI,MAP,CF,DA	log $7Q_{10}$ = f(DA, MAP, SI) $7Q_{10}$ = f(DA, MAP, CF)
Boyer, 1977	12	G	Regression	DA,CO,EL,LAT,LNTH,WF, T_{10},R_{10}	In ($7Q_{10}$) = f(CO, LNTH, WF, T_{10}, R_{10})
Env. Can., 1978	11	G		DA,R,AS,AL,ALS,OB,LEN, DD,SLP,EL,MAP	Correlation Matrix only produced
Inst. of Hydrology, 1980		G	Regression	Q_{95}(10),BFI,DA,MAP,LNTH	$Q_{95}(10) = F((BFI)^{.5}, (DA)^{.5}, (MAP)^{.5})$ $Q_{95}(10) = F((BFI)^{.5}, (DA)^{.5}, (LNTH)^{.5})$ (100_2) = f(BFI) (100_2) = f(BFI, MAP)
MacLaren Plansearch, 1981	9	Eye Fit	Regression	DA,SI,ALS	Q_1 = f(DA, SI, ALS) Q_4 = f(DA, SI, ALS)
Condie, 1983	74	G	Regression	DA,MAP,BFI	MED(10) = f(DA, BFI) GRADMEN = f $((MED(10))^{.5})$
Inst. of Hydrology, 1986	232	LN	Regression	BFI,MAP,ACLS	$(Q95(10)^{1/4}$ = f(BFI, MAP, ACLS) $(Q95(10)^{1/4}$ = f(BFI, ACLS)
Vogel & Kroll, 1990	23	LN	Regression	DA,H	7Qy = f(DA, H)
Cumming Cockburn, 1990	65	3PLN	Regression	DA,BFI,LNTH	nQy = f (DA, BFI, LNTH)

Recent investigations (Cumming Cockburn Limited, 1990) also recommended that the Ministry of the Environment should continue use of the $7Q_{20}$ as a prime indicator of low flows for the Province of Ontario.

3.0 DATA BASE

3.1 General

The Central and Southeastern regions identified by the Ministry of Environment define the study area. One hundred and twenty-five hydrometric stations were identified in the region for this analysis based upon the period of record and other station characteristics. Low flow characteristics for 73 of these stations were analysed to develop estimation techniques. Twenty-one of those remaining were set aside for testing of results. The remaining stations were omitted from the study based on selective screening criteria. (Station screening and selection is discussed in Section 3.2.2.)

Low flow characteristics at each station were retrieved from our inhouse computerized data base. The methodology for analysing extreme low flows and determining relevant recurrent intervals is discussed in the Low Flow Characteristics in Ontario report, Cumming Cockburn Limited, Ministry of the Environment, 1988 (Appendices A, B and C) and the results summarized on Figures 3.1 and 3.2 of this report. Relevant physiographic and meteorological characteristics were also determined as discussed in Section 3.3.

3.2 Extreme Value Analysis

Moving average low flows (n-day) were determined and extracted for each year of the available data base. Average extreme low flows were determined and extracted for the 1, 3, 7, 15 and 30 day durations and are available as part of the background files.

An extreme value analysis was then undertaken for each of the 1, 3, 7, 15 and 30 day durations for each of the stations. The results of the analysis are presented elsewhere (Cumming Cockburn Limited, 1988). The SPSS program was then used to produce general statistics of the data base including the mean, standard deviation and coefficient of skew of the available low flow samples for different durations. These general statistics are summarized in Tables 3.1 and 3.2.

TABLE 3.1

SUMMARY OF STATISTICS FOR DATA USED IN THE EXTREME VALUE ANALYSIS

Region	*No. of Stations	Day Duration	Mean m^3/s	Standard Deviation m^3/s	Skew	Coefficient of Variation	Minimum Flow m^3/s	No. of Years
Ontario	344	1	10.89	3.97	.82	.71	4.07	28
	344	3	12.50	4.02	.78	.66	5.78	28
	344	7	13.80	4.06	.75	.62	6.61	28
	344	15	14.32	4.01	.78	.59	7.27	28
	341	30	N/A	3.44	.84	.57	N/A	28
Central	76	1	1.45	.65	.39	.45	.52	24
	76	3	1.65	.66	.42	.42	.63	24
	76	7	1.89	.67	.44	.40	.81	24
	76	15	2.14	.73	.51	.41	1.01	24
	76	30	2.53	.91	.61	.40	1.18	24
Southeastern	49	1	27.36	7.36	1.62	1.05	12.22	28
	49	3	30.86	6.99	1.50	.96	18.58	28
	49	7	33.53	7.69	1.48	.93	20.97	28
	49	15	33.53	6.68	1.45	.89	22.51	28
	49	30	N/A	1.51	1.57	.90	N/A	28

TABLE 3.2

UNIT AREA AVERAGE LOW FLOWS

Region	Day Duration	Recurrence Interval (years)									
		2 Mean (Std. Deviation) 1/s/km²		5 Mean (Std. Deviation) 1/s/km²		10 Mean (Std. Deviation) 1/s/km²		20 Mean (Std. Deviation) 1/s/km²		50 Mean (Std. Deviation) 1/s/km²	
Ontario	1	1.59	(1.40)	1.10	(1.12)	0.89	(1.00)	0.75	(0.92)	0.62	(0.85)
	3	1.74	(1.54)	1.24	(1.25)	1.02	(1.12)	0.87	(1.02)	0.73	(1.93)
	7	1.91	(1.90)	1.38	(1.39)	1.15	(1.24)	0.99	(1.14)	0.84	(1.03)
	15	2.08	(1.79)	1.52	(1.49)	1.29	(1.34)	1.12	(1.24)	0.97	(1.13)
	30	2.31	(1.88)	1.68	(1.57)	1.43	(1.43)	1.25	(1.32)	1.09	(1.22)
Central	1	2.18	(1.70)	1.63	(1.44)	1.38	(1.32)	1.19	(1.23)	1.00	(1.14)
	3	2.35	(1.83)	1.80	(1.56)	1.54	(1.42)	1.34	(1.30)	1.14	(1.17)
	7	2.53	(1.92)	1.97	(1.67)	1.70	(1.53)	1.50	(1.42)	1.30	(1.29)
	15	2.76	(2.02)	2.16	(1.78)	1.88	(1.65)	1.68	(1.54)	1.48	(1.42)
	30	3.14	(2.17)	2.44	(1.93)	2.13	(1.80)	1.91	(1.70)	1.70	(1.59)
Southeastern	1	0.97	(1.31)	0.64	(1.02)	0.51	(0.89)	0.43	(0.80)	0.37	(0.72)
	3	1.08	(1.49)	0.74	(1.22)	0.62	(1.10)	0.54	(1.02)	0.48	(0.95)
	7	1.21	(1.61)	0.84	(1.33)	0.71	(1.21)	0.63	(1.13)	0.56	(1.06)
	15	1.32	(1.65)	0.92	(1.38)	0.78	(1.27)	0.70	(1.18)	0.63	(1.11)
	30	1.13	(1.05)	0.72	(0.80)	0.59	(0.70)	0.51	(0.64)	0.46	(0.60)

3.2.1 Summary Maps of Gauged Information

Selected low flow characteristics were extracted and summarized on a map for the study area (see Figures 3.1 and 3.2). The station locations are identified by a $\triangle$ located on the rivers at the point of discharge measurement and the selected data is summarized in an information box.

The stations (on Figures 3.1 and 3.2) are identified by the 7 digit Water Survey Number and this is followed by a regulation code. The "R" indicates that data collected at the station is affected by regulation, "N" means the station data are natural or non-regulated. The boxes on the left from the top refer to the average 7 day flow (m^3/s) with a recurrence interval of 2, 5, 10 and 20 years, followed by the minimum average 7 day flow and the period of record for the station. The values shown on the right are the flows (m^3/s) equalled or exceeded for the available period of record 5, 50, 75, 95 and 99 percent of the time followed by the station drainage area in km^2.

Station names are also listed along with the station numbers for identification purposes on Figures 3.1 and 3.2.

3.2.2 Screening Results

The stations which were not considered to possess a suitable low flow data base for the purposes of this investigation were not included in the regionalization analysis. These stations were excluded for the following reasons:

i) Multiple Stations

It was determined that large river systems may have several streamflow gauges at several locations along the channel. The use of all such highly correlated data could adversely bias the development of regionalization methods. Therefore, only representative gauges for such streams were retained for further analysis. A few of the multiple stations were used for testing the developed techniques.

ii) Heavily Regulated

Low flows on heavily regulated streams (i.e. St. Lawrence, Ottawa and Trent River systems) are affected through the use of reservoirs for low flow augmentation. Since the main focus of this study is to produce a method for investigating low flows for ungauged watersheds, stations indicating a high degree of regulation were excluded from the data base. The Water Survey of Canada identifies gauges as regulated (R) or natural streams (N). The degree of regulation is not quantified for these regions. Of the 125 stations, 75 were identified as "regulated" to some degree. Therefore, objective screening of the "regulated" stations was undertaken (i.e. stations on the Trent, Ottawa and St. Lawrence system were removed). The remaining "regulated" stations were retained and assigned a regulatory code representing regulation or non-regulation. Subsequent simple correlation analysis (between the regulatory codes and the low flow statistics) confirmed that these stations could be retained in the data set due to insignificant levels of correlation. Future studies should investigate and quantify degrees of regulation and possible techniques to deregulate flow series.

iii) Statistical Tests

Statistical data analysis tests were undertaken as described in more detail in Regional Analysis of Low Flow Characteristics for Southwestern and West Central Regions by Cumming Cockburn Limited (1990). The available test statistics were recently made available as part of the LFA (Pilon and Jackson, 1987) low flow package.

In general, it was found that a significant number of stations "failed" the non-parametric tests. Therefore, taken over the entire data base, application of these tests has indicated that the available data base of extreme low flows may exhibit some trend and dependence with some possibility of non-random characteristics.

The data were further analysed by subdivision of the available data set according to length of record (i.e. ≥20 years and <20 years) and according to regulation code. However, it was found that neither the length of record, nor the possible effects of regulation could account for the conclusions of the test results. One explanation could be that the available record lengths are too short to permit reasonable application and interpretation of these non-parametric test results. Another explanation could relate to seasonal effects on low flows; i.e.

low flows in the winter and summer may belong to distinct populations. A stronger possibility is that the available low flow data sets do exhibit trend and non-random characteristics, which could possibly be attributed to slow cyclic change in groundwater levels or to climatic trends. Additional testing was beyond the scope of the current investigations. However, further studies are recommended since these results may call into question the basic assumptions underlying application of the extreme value analysis technique for analysis of low flow characteristics.

Stations not passing the statistical screening were not removed from the analysis as there would be too few stations remaining.

3.2.3 Summary of Data Analysis and Low Flow Characteristics

Application of various non-parametric tests was undertaken for the available data base for the first time in Ontario.[1] The test results indicate that the available data base of extreme low flows may exhibit some trend and dependence with some possibility of non-random characteristics. Previous widespread application of the tests utilized have not been found in the literature for low flows. The average length of record for the stations analysed in these regions is 26 years. It is possible that the available record lengths are too short to permit reasonable application and interpretation of these non-parametric test results. Another possibility, which should be investigated in more detail, is that the available low flow data sets do exhibit trend and non-random characteristics. The latter could possibly be attributed to slow cyclic changes in groundwater levels, seasonal effects, or climatic trends. This should be investigated in more detail since the underlying assumptions for application of the extreme value distribution and subsequent regression analyses are called into question.

The Gumbel Extreme Value Distribution was generally found to adequately fit the available low flow series for various low flow durations. However, data for some stations could not be fit due to either a large number of zero flows, numerical computational problems, or very large low flows recorded at some locations. Additional research investigations are required to develop suitable low flow analysis techniques for such locations.

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[1] The analysis was done in conjunction with "Low Flow Characteristics in Ontario Study", Cumming Cockburn Limited, 1988

Extreme value analyses were undertaken on an annual basis for 125 stations. A total of 73 stations were retained for analysis and 21 for additional testing of results.

The data analyses were undertaken for both regulated and unregulated data series. Therefore, care should be taken in comparison and interpretation of results, notably for data series which may include the effects of regulation.

Figures 3.1 and 3.2 summarized the following low flow characteristics:

- 7 day extreme values for the 2, 5, 10 and 20 year recurrence intervals
- flows which were equalled or exceeded over the available period 5, 50, 75, 95 and 99 percent of the time.

Data analysis and management techniques are now available which would allow efficiently updating the present analyses on a frequent basis. In our opinion, the low flow analyses should be updated every five years in order to provide reasonably accurate information for investigation requiring low flow information.

3.3 Physiographic and Meteorologic Data

3.3.1 Criteria

Several criteria were used to identify physiographic and climatic parameters which might be suitable for use in regionalizing low flow characteristics. These are discussed as follows:

i) Statistical Significance

When undertaking a multivariate analysis, the variables chosen must make a contribution to explaining the variance of the low flows. The significant experience in undertaking similar investigations (discussed in Section 2.0) was used to identify parameters which have proven to be statistically significant in predicting low flows.

ii) Physical Characteristics

Wherever possible, variables should be selected based on hydrologic significance. That is, the parameters should have some physical meaning with regard to estimates of low flows.

iii) Reliability of Computation

It is preferable to select parameters which can easily be computed in a reliable manner by users who may not be familiar with regression procedures or the details of the statistical concepts. Therefore, from a practical point of view, it was desirable to make the parameter estimation procedure as uncomplicated as possible in order to minimize computation errors when applying the technique.

3.3.2 Parameters

The parameters selected for use in this study are listed as follows:

Hydrometeorologic Data	Symbol
Index of mean annual precipitation at gauge location (mm)	MAP
Index of mean annual snowfall at gauge location (cm)	MAS
Index of mean annual runoff at gauge location (mm)	MAR
Index of mean annual evaporation at gauge location (mm)	EVA

Physiographic Data	
Drainage area (km^2)	DA
Index of area controlled by lakes and swamps	ACLS
Length of main channel (km)	LNTH
10/85 channel slope (m/m)	SLP
Base Flow Index (dimensionless ratio)	BFI
Regulation Index (0 - natural, 1 - regulated)	RN
Groundwater fluctuation (m)	GW

Detailed parameter definition and methodology for derivation is discussed in the following sections:

DA (km^2)

The watershed drainage area was obtained from records published by the Water Survey of Canada.

ACLS (%)

An index representing the percentage of the drainage area controlled by lakes and swamps (ACLS) was obtained from records available in Regional Flood Frequency Analysis (Moin and Shaw, 1986) and published by Environment Canada.

LNTH (km)

The length of the main channel was recorded from the Regional Flood Frequency Analysis (Moin and Shaw, 1986) and published by Environment Canada. The lengths for some stations were not previously calculated. For these stations the lengths were scaled from review of Water Survey of Canada watershed boundaries and rivers on 1:50,000 NTS maps.

SLOPE (m/km)

The 10/85 slope (SLP) recommended by the U.S. Geological Survey was available for some stations from the published literature Regional Flood Frequency Analysis (Moin and Shaw, 1986). The 10/85 slope is calculated by taking the elevation difference at the 10% and 85% points along the channel length. The slopes for some stations were not previously calculated. For these stations the slopes were determined by creating an elevation distance table from review of Water Survey of Canada watershed boundaries on 1:50,000 NTS maps.

Base Flow Index (BFI) (Dimensionless Ratio)

the drainage basin. BFI is defined as:

$$BFI = \frac{\text{Total Volume of Base Flow}}{\text{Total Volume of Runoff}}$$

The median values calculated for all Ontario gauging stations having at least 2 years of continuous daily discharge data were plotted at the corresponding drainage basin centroids using 1:600,000 scale base maps for Southern Ontario and isolines drawn. The centroids were located by eye after delineating the drainage area. The isoline map was prepared to help provide estimates of BFI for ungauged basins when applying the regression equations (Regional Flood Frequency Analysis, Moin and Shaw, 1986). All estimates of BFI from the isoline maps must be made by first locating the basin centroid and then projecting this point to the closest point on the main channel. The BFI is then interpolated from the isolines at this location on the main channel. A better BFI estimate will be obtained for large basins and in areas where the isolines are very close together, if an average value of BFI, weighted by the area between isolines, is taken over the entire drainage basin.

RN

Regulation code (i.e. an assessment of the degree of regulation a stream is determined to have):

0 - Natural, non-regulated
1 - Regulated

NOTE: Heavily regulated stations were not included in the analysis and simple correlation analysis indicated insignificant levels of correlation with the observed low flows for the stations remaining.

GW (m)

An index for the groundwater table fluctuation was developed using the data reported in the Environment Atlas of Observation Wells in Ontario published by the Ontario Ministry of the Environment, 1980. Only sparse well observation information is available but nevertheless whatever was available was used. The maximum fluctuation of the water table for a well was calculated from the observed maximum and minimum water table depths.

MAP (mm)

An index of mean annual precipitation was developed with reference to available publications (MNR, 1984, Environment Canada, 1978 and Flood Frequency Analysis, Moin and Shaw, 1986)). The index of mean annual precipitation is interpolated for each watershed used in the analysis at the gauge location.

MAS (mm)

An index of mean annual snowfall was obtained from available information published by the Ministry of Natural Resources (MNR, 1984) and Fisheries and Environment Canada , 1978. An index map was used to derive the snowfall index for each hydrometric gauge. This index represents total annual snowfall for each watershed. The index was determined at the gauge location.

MAR (mm)

The index of mean annual runoff is expressed as a depth of water averaged over the drainage basin area. The isolines of runoff were obtained from existing information published by Environment Canada and adopted by the Ministry of Natural Resources (Sangal and Kallio, 1977, MNR, 1984 and Flood Frequency Analysis, Moin and Shaw, 1988). The mean annual runoff index was derived for each hydrometric station at the gauge location.

EVA (mm)

An index for the mean annual evaporation was obtained from the publications by Fisheries and Environment Canada, 1978. The mean annual evaporation index was derived for each hydrometric station at the gauge location.

3.3.3 Summary of Physiographic and Meteorologic Data

Tables 3.3(a) and 3.3(b) summarize the parameters which were determined for each station remaining after screening for the Central and Southeastern Regions, respectively. Table 3.4

3.3.3 Summary of Physiographic and Meteorologic Data

Tables 3.3(a) and 3.3(b) summarize the parameters which were determined for each station remaining after screening for the Central and Southeastern Regions, respectively. Table 3.4 summarizes the mean, range and other simple statistics of the data base for the Central, Southeastern and combined regions.

TABLE 3.3 (a)

DATA BASE FOR THE CENTRAL REGION

STATION	GW	RN	YRS	MAP	MAS	MAR	SLP	EVA	DA	BFI	LNTH	ACLS	7Q2	7Q20
02EB008	0.910	1	41	990	290	516	0.020	700	1390	0.79	48.8	100	4.508	1.459
02EB013	0.910	0	46	1000	220	500	4.010	665	593	0.68	38.0	30	4.738	1.360
02EC002	0.910	0	67	890	270	454	1.020	740	1520	0.69	94.3	0	1.690	0.720
02EC008	0.460	1	10	880	170	237	3.302	785	274	0.59	30.0	3	0.267	0.092
02EC009	0.300	1	22	850	160	228	1.314	800	181	0.45	29.0	70	0.293	0.149
02EC011	0.940	0	16	820	230	323	0.420	780	282	0.46	55.3	74	0.250	0.120
02EC012	0.910	1	13	860	240	254	1.640	780	324	0.50	32.5	95	0.360	0.280
02EC101	0.790	1	12	810	200	468	4.610	795	24	0.82	32.0	4	0.250	0.180
02ED003	0.370	0	34	870	260	255	1.900	790	1180	0.55	61.8	51	2.260	1.450
02ED005	0.430	1	19	880	270	424	2.230	785	295	0.61	50.5	35	0.970	0.570
02ED007	0.910	0	17	1000	300	408	1.990	740	177	0.63	28.0	0	0.960	0.780
02ED009	0.150	0	11	890	270	295	1.620	765	95	0.33	15.5	23	0.030	0.010
02ED011	0.910	1	14	980	220	438	2.177	725	168	0.65	14.0	5	0.463	0.217
02ED100	0.270	1	14	820	230	209	2.750	800	86	0.57	17.8	0	0.150	0.060
02ED103	0.380	0	14	850	260	380	4.820	790	195	0.71	37.5	0	0.880	0.700
02HB001	3.050	1	58	810	120	271	1.800	810	205	0.45	15.0	0	0.603	0.317
02HB005	0.550	1	24	780	130	394	3.360	825	96	0.53	16.5	0	0.230	0.060
02HB008	0.270	1	20	790	160	324	4.290	815	127	0.57	21.0	0	0.360	0.230
02HB011	0.370	1	19	790	140	361	2.870	830	235	0.64	30.0	3	0.450	0.330
02HB013	3.050	1	20	870	140	325	5.927	800	62	0.65	9.0	40	0.211	0.144
02HC005	0.080	1	35	790	140	350	3.810	815	88	0.40	18.0	0	0.160	0.058
02HC006	0.080	1	29	790	150	349	7.470	810	249	0.54	29.5	38	0.740	0.370
02HC012	0.430	1	25	780	200	271	5.350	810	169	0.60	24.6	24	0.480	0.310
02HC013	0.060	0	17	780	140	338	6.000	810	88	0.43	15.2	0	0.230	0.080
02HC017	1.219	0	19	790	160	285	3.378	820	63	0.26	20.3	0	0.046	0.003
02HC018	0.183	0	24	800	140	258	7.870	810	106	0.46	21.5	2	0.104	0.042
02HC019	0.610	0	24	790	140	402	9.420	810	94	0.58	17.5	7	0.461	0.327
02HC022	0.457	1	26	800	150	239	2.910	810	186	0.37	28.1	13	0.138	0.069
02HC023	0.366	0	25	790	180	242	4.438	820	62	0.57	11.8	5	0.183	0.125
02HC024	0.061	0	25	780	140	380	3.563	820	316	0.49	37.5	3	1.387	1.162
02HC025	0.366	0	25	780	170	254	1.571	820	303	0.59	45.0	5	0.820	0.591
02HC028	0.610	1	23	780	140	314	3.302	810	78	0.34	17.5	0	0.089	0.045
02HC029	0.488	1	23	780	140	347	4.212	820	130	0.43	20.0	0	0.418	0.257
02HC030	0.610	1	21	780	140	323	4.410	800	204	0.24	38.0	0	0.228	0.142
02HC031	0.488	1	18	790	180	209	4.168	820	148	0.23	24.0	0	0.009	0.000
02HC032	0.549	1	21	790	180	189	1.841	810	95	0.44	21.0	19	0.071	0.052
02HC033	0.488	1	21	780	140	342	3.267	820	71	0.25	29.5	0	0.096	0.045
02HC034	0.488	0	18	780	140	202	6.190	820	194	0.17	22.0	0	0.006	0.000
02HD003	0.488	1	28	800	140	527	3.178	790	67	0.70	15.5	0	0.484	0.299
02HD006	0.488	1	28	810	140	483	5.680	790	83	0.59	22.0	7	0.503	0.353
02HD009	0.488	0	22	810	140	359	1.153	790	83	0.62	15.0	0	0.341	0.228
02HD010	0.488	0	22	810	140	408	8.126	790	65	0.62	17.5	0	0.316	0.195
02HD012	0.488	0	11	810	160	449	9.434	790	232	0.66	21.0	0	1.388	1.036
02HH002	0.549	1	15	900	180	416	2.540	750	326	0.65	30.0	100	0.702	0.177
02HJ001	0.488	0	25	790	180	322	2.714	780	110	0.40	18.5	89	0.076	0.025
02HJ003	0.366	1	20	790	170	320	1.065	780	282	0.62	28.5	77	0.156	0.023
02HK005	0.427	1	19	910	180	462	0.920	770	456	0.76	35.5	87	0.803	0.226
02HK006	0.427	1	14	900	170	424	2.743	770	541	0.62	60.0	30	0.157	0.021

TABLE 3.3 (b)

DATA BASE FOR THE SOUTHEASTERN REGION

STATION	GW	RN	YRS	MAP	MAS	MAR	SLP	EVA	DA	BFI	LNTH	ACLS	7Q2	7Q20
02HE002	2.13	1	13	850	170	417	0.880	790	114	0.32	15.0	95	0.002	0.000
02HK005	0.91	1	14	910	180	462	0.920	765	456	0.76	35.5	87	0.803	0.226
02HK006	1.16	1	13	920	170	353	3.441	760	541	0.62	31.0	5	0.157	0.021
02HL001	2.74	1	67	810	170	361	0.960	780	2620	0.71	87.0	56	1.477	0.582
02HL003	2.74	1	18	850	170	384	2.200	770	401	0.60	66.5	69	0.450	0.061
02HM002	4.27	1	30	880	180	375	7.144	770	189	0.65	20.0	100	0.322	0.039
02HM003	4.27	1	24	850	180	366	1.530	780	891	0.77	112.4	79	0.145	0.034
02HM005	4.27	0	10	900	180	540	0.960	775	155	0.49	27.0	35	0.025	0.000
02HM006	4.27	1	13	900	180	463	0.800	775	150	0.63	40.0	84	0.095	0.039
02HM007	4.27	1	10	880	180	403	0.610	770	694	0.78	50.5	97	1.159	0.355
02KA003	0.30	0	20	830	190	260	12.190	635	7	0.50	5.0	50	0.001	0.000
02KB001	0.30	1	67	800	190	362	1.360	660	4120	0.88	107.6	59	11.292	6.560
02KC009	0.30	1	61	800	190	355	3.217	715	2380	0.68	90.0	50	4.762	2.830
02KF011	0.37	0	12	810	200	358	0.280	720	269	0.33	35.0	2	0.059	0.010
02KF012	0.61	1	11	810	200	375	1.720	720	203	0.61	37.5	61	0.278	0.181
02KF013	0.85	1	11	800	200	387	1.280	735	280	0.67	32.5	45	0.150	0.021
02KF014	0.55	1	12	800	180	358	1.725	740	277	0.59	53.0	95	0.109	0.000
02LA004	0.61	1	34	810	200	316	0.940	735	3830	0.52	92.5	47	5.705	3.118
02LA006	0.61	1	13	820	200	412	0.140	740	409	0.41	63.0	63	0.076	0.008
02LA007	0.61	0	14	850	190	380	0.610	740	559	0.38	60.5	17	0.086	0.012
02LB006	1.83	0	35	820	190	420	0.650	740	433	0.30	36.3	0	0.195	0.089
02LB008	0.30	0	25	830	190	478	0.540	730	440	0.30	46.2	0	0.161	0.105
02LB017	0.91	0	9	800	200	395	1.016	750	69	0.30	15.0	0	0.529	0.097
02LB022	2.44	0	9	800	200	396	2.540	745	152	0.30	34.0	0	0.027	0.001
02MC001	0.30	0	26	800	200	422	0.293	745	404	0.37	26.0	0	0.044	0.004

TABLE 3.4

SUMMARY OF SIMPLE STATISTICS OF THE METEOROLOGICAL AND PHYSIOGRAPHIC DATA

Central Region

Variable	Mean	Std. Dev.	Skewness	S.E. Skew	Range	Minimum	Maximum	N	Label
GW	0.61	0.57	3.34	0.34	2.99	0.06	3.05	48	max wt fluctuation (m)
RN	0.6	0.49	-0.44	0.34	1	0	1	48	reg code 0-N 1-R
YRS	23.21	11.05	2.19	0.34	57	10	67	48	years of record
MAP	831.46	63.08	1.45	0.34	220	780	1000	48	mean annual precipitation (mm)
MAS	180.21	48.75	1.03	0.34	180	120	300	48	mean annual snowfall (mm)
MAR	344.33	90.14	-0.18	0.34	338	189	527	48	mean annual runoff (mm)
SLP	3.6	2.26	0.92	0.34	9.41	0.02	9.434	48	slope (m/km)
EVA	791.15	33.15	-1.86	0.34	165	665	830	48	mean annual evaporation (mm)
DA	258.26	315.49	2.96	0.34	1495.7	24.3	1520	48	drainage area (km^2)
BFI	0.53	0.15	-0.52	0.34	0.65	0.17	0.82	48	base flow index
LNTH	28.76	15.84	1.96	0.34	85.3	9	94.3	48	stream length
ACLS	21.65	32.24	1.42	0.34	100	0	100	48	area controlled by lakes and swamps (%)
Q2	0.64	0.96	3.29	0.34	4.73	0.006	4.738	48	7Q2
Q20	0.32	0.39	1.79	0.34	1.46	0	1.459	48	7Q20

Southeastern Region

Variable	Mean	Std. Dev.	Skewness	S.E. Skew	Range	Minimum	Maximum	N	Label
GW	1.68	1.53	0.85	0.46	3.97	0.3	4.27	25	max wt fluctuation (m)
RN	0.64	0.49	-0.62	0.46	1	0	1	25	reg code 0-N 1-R
YRS	22.84	17.68	1.73	0.46	58	9	67	25	years of record
MAP	837.2	39.64	0.85	0.46	120	800	920	25	mean annual precipitation (mm)
MAS	187.2	11	-0.21	0.46	30	170	200	25	mean annual snowfall (mm)
MAR	391.92	55.47	0.44	0.46	280	260	540	25	mean annual runoff (mm)
SLP	1.92	2.59	3.14	0.46	12.05	0.14	12.19	25	slope (m/km)
EVA	743.4	35.79	-1.55	0.46	155	635	790	25	mean annual evaporation (mm)
DA	801.72	1144.85	2.14	0.46	4113	7	4120	25	drainage area (km^2)
BFI	0.54	0.18	0.04	0.46	0.58	0.3	0.88	25	base flow index
LNTH	48.76	29.44	0.8	0.46	107.4	5	112.4	25	stream length
ACLS	47.84	35.91	-0.13	0.46	100	0	100	25	area controlled by lakes and swamps (%)
Q2	1.12	2.55	3.21	0.46	11.29	0.001	11.292	25	7Q2
Q20	0.58	1.49	3.29	0.46	6.56	0	6.56	25	7Q20

Combined Regions

Variable	Mean	Std. Dev.	Skewness	S.E. Skew	Range	Minimum	Maximum	N	Label
GW	0.97	1.12	2.06	0.28	4.21	0.06	4.27	73	max wt fluctuation (m)
RN	0.62	0.49	-0.49	0.28	1	0	1	73	reg code 0-N 1-R
YRS	23.08	13.56	1.95	0.28	58	9	67	73	years of record
MAP	833.42	55.93	1.38	0.28	220	780	1000	73	mean annual precipitation (mm)
MAS	182.6	40.04	1.02	0.28	180	120	300	73	mean annual snowfall (mm)
MAR	360.63	82.74	-0.09	0.28	351	189	540	73	mean annual runoff (mm)
SLP	3.02	2.49	1.42	0.28	12.17	0.02	12.19	73	slope (m/km)
EVA	774.79	40.8	-1.17	0.28	195	635	830	73	mean annual evaporation (mm)
DA	444.38	754.52	3.56	0.28	4113	7	4120	73	drainage area (km^2)
BFI	0.53	0.16	-0.26	0.28	0.71	0.17	0.88	73	base flow index
LNTH	35.61	23.33	1.6	0.28	107.4	5	112.4	73	stream length
ACLS	30.62	35.57	0.76	0.28	100	0	100	73	area controlled by lakes and swamps (%)
Q2	0.8	1.68	4.33	0.28	11.29	0.001	11.292	73	7Q2
Q20	0.41	0.92	4.89	0.28	6.56	0	6.56	73	7Q20

4.0 ANALYSES OF EXISTING TECHNIQUES

4.1 General

The previous results (Southwestern and West Central Regions, CCL, 1990) indicated that:

- estimates of low flow characteristics could not be improved by subdividing the area into sub-regions (perhaps due to the relatively small amount of available data), and
- in regard to estimating accuracy, the methods ranked as follows:

  i) Regression
  ii) Mapped Isolines
  iii) Index Relationships
  iv) Nearby gauge proration

To assess the applicability of the previous results extrapolated to the present study area, the previously developed techniques with the previously determined coefficients and constants were utilized to predict low flow characteristics for stations located in the Central and Southeastern Regions.

4.2 Summary of Analysis

This analysis is summarized in Table 4.1 for the Central, Southeastern and the combined regions. (A detailed analysis is given in Appendix E.) The results indicate that the ranking of the technique remains almost the same as the previous test stations indicated [(i.e. i) Regression, ii) Index Relationships, iii) Mapped Isolines, iv) Unit Area Proration techniques.]

The Nash-Sutcliffe R^2 values were computed and indicated similar results for application of the regression equation techniques compared to the previous study (i.e. R^2 for estimation of $7Q_{20}$ ranging from 0.29, 0.75 and 0.70 for the Central, Southeastern and combined region analysis). In addition, the Index method and Isoline method are reversed in ranking. This could be due to a different relationship between BFI and unit area low flows for these

TABLE 4.1

SUMMARY OF TESTING PREVIOUS LOW FLOW ESTIMATION TECHNIQUES

NASH-SUTCLIFFE R^2

FOR REGIONAL ANALYSIS

Estimating Method and Target Characteristic	Central	Southeastern	Combined
Regression Equation			
$7Q_2$	0.24	0.88	.75
$7Q_{20}$	0.29	0.75	.70
Index Method			
$7Q_2$	0.22	0.59	.53
$7Q_{20}$	0.04	0.42	.39
Isoline Method			
$7Q_{20}$	-0.09	-0.25	-0.20
Station Proration			
$7Q_{20}$	-0.94	-1.41	-1.29

regions. It is interesting to note that in all regions the unrefined techniques still produce better results than nearby gauge proration techniques historically used.

Table 4.2 summarizes the average $7Q_{20}$ low flow rates and standard deviations for the observed (i.e. statistically determined flows) and estimation techniques for each region.

The Index method produced lower average low flows for all three regional groups. This indicates that drainage areas in these regions produce more low flow per unit area compared to the values in Southwestern and West Central Ontario from which the index curves were developed.

The nearby gauge proration technique and isoline technique both produced average values greater than the observed values for these regions. This preliminary isoline analysis was based on conversion of BFI isolines to unit area low flows (i.e. the comparison was developed from data from the Southwestern and West Central regions). This would appear to indicate that BFI values in the Central and Southeastern region produce higher low flows than similar BFI values in the Southeastern and West Central regions. Conversely, the low flow/BFI relationship may be being affected by Basin Storage BFI interrelationships (see Section 2.1).

The regression technique estimated lower average low flows in the Central region and the two regions combined. However, higher average low flows were predicted for the Southeastern Region. This suggests that the Central and Southeastern regions are likely to be distinct from Southwestern, West Central Ontario and distinct from each other.

In most cases, estimation techniques for the low flows with smaller recurrence intervals (i.e. $7Q_2$) resulted in higher Nash-Sutcliffe R^2 values than did the low flows with less frequent recurrence intervals (i.e. $7Q_{20}$). Therefore, it might be useful to consider that further investigation should examine using $7Q_2$ as the predictor and then some relationship to produce $7Q_{20}$ values.

3 Summary

- Nash-Sutcliffe R^2 values are quite reasonable for the regression equations for Southeastern and the combined regions.

TABLE 4.2

CHARACTERISTICS OF OBSERVED AND SIMULATED $7Q_{20}$ VALUES FROM PREVIOUS TECHNIQUES

Techniques	Central		Southeastern		Combined	
	Average $7Q_{20}$	Standard Deviation $7Q_{20}$	Average $7Q_{20}$	Standard Deviation $7Q_{20}$	Average $7Q_{20}$	Standard Deviation $7Q_{20}$
Observed	.31	.39	.64	1.54	.41	.94
Regression	.22	.20	1.0	1.9	.47	1.14
Index	.11	.10	0.4	0.47	.19	.30
Isoline	.38	.56	1.5	2.8	.72	1.73
Unit	.36	.53	0.9	2.4	.53	1.46

- None of the estimation techniques produced favourable results in the Central Region.
- Low flows (i.e. $7Q_{20}$ are lower for methods based only on drainage area and higher for methods based on BFI values. Hence, coefficients for these parameters as they relate to low flows in the Central and Southeastern regions are probably significantly different than from the Southwestern West Central regions whence they were developed.
- The large difference in Nash Sutcliffe R^2 values for the Central and Southeastern regions indicate they may be distinct with respect to low flow characteristics
- The isoline method based upon BFI values did not appear to provide a good estimation technique
- The Nash-Sutcliffe R^2 results indicate that all techniques are better predictions than use of the gauge unit area proration technique which is in common use.

5.0 REGIONALIZATION OF LOW FLOW CHARACTERISTICS

5.1 General

Four alternative methods of providing regional estimates of low flow characteristics were considered. They are; Multiple Linear Regression (Section 5.2), Index Method (Section 5.3), Mapped Isolines of unit low flows (Section 5.4), and proration from nearby gauges (unit area technique) (Section 5.5). Emphasis was placed on determining $7Q_{20}$ and $7Q_2$ as these flows were identified to be the key low flow statistics required by the Ministry of the Environment.

5.2 Regression

5.2.1 General

Multiple linear regression equations take the following general form:

$$Y = a_0 + a_1Y_1 + a_2Y_2 + \ldots\ldots + a_nY_n \tag{5.1}$$

where $Y =$ the dependent variable (e.g. $7Q_{20}$)

$Y_1, Y_2 \ldots Yn =$ the independent variables (e.g. physiographic and meteorologic watershed characteristics)

$a_0, a_1 \ldots a_n =$ regression coefficients

In order to obtain a more accurate regression equation, it is sometimes necessary to transform the data by taking logarithms, square roots, cubes, etc. The transformations considered for this investigation are discussed in Section 5.2.3.

A number of regression procedures are available, including development of all possible equations, forward selection, backward selection, stagewise regression and stepwise regression. The stepwise regression procedure is generally recommended for use in practical applications (Draper and Smith, 1981) and was, therefore, adopted for the purposes of this investigation.

5.2.2 Methodology

The regression equations were developed utilizing the stepwise multiple linear regression procedure available in the Statistical Package for the Social Sciences (SPSS) (Nie, 1975). More specifically, the regression subprogram has been used and has the following special features:

1) Out of various procedures for selecting variables, including forward selection, backward elimination and the stepwise selection, the last one which is really a combination of backward and forward procedures, was adopted for this investigation as it is the most commonly used procedure for this type of study.
2) Variable selection - all independent variables can be stored and then only those variables desired for a particular analysis called up and used according to the desired form of the equation
3) Combination of variables - variable transformation and new variables may be computed from existing variables
4) Transformations - the variables may be transformed (e.g. square root, logarithmic, squared, etc.) in order to more nearly linearize the relationships
5) Calculation of statistics - the SPSS regression package allows calculation of numerous regression coefficients, statistics and residual statistics (difference between observed and calculated values). Also possible are scatter plots of residuals and statistical tests for residual analysis, etc.

The regression constant and regression coefficients are determined in order to minimize the sum of the square residuals. The residuals are the difference between the observed, dependent variable and the prediction by the regression equation. The SPSS program automatically includes those independent variables which meet the 95% confidence level based on the computed values of the F statistic. Only those variables which meet the specified level at any given step are retained in the regression equation and all those variables which fall below the specified level are deleted from the regression equation. By specifying an appropriate subcommand, a variable can be forced in or out of the regression equation.

The entry of the variables can also be controlled by specified the maximum number of steps and redefining the tolerance criteria. Variables must pass both tolerance and minimum tolerance tests in order to enter and remain in a regression equation. Tolerance is the

proportion of the variance of a variable in the equation that is not accounted for by other independent variables in the equation. The minimum tolerance of a variable not in the equation is the smallest tolerance any variable already in the equation would have if the variable being considered were included in the analysis. If a variable passes the tolerance criteria, it is further tested according to the method in effect.

5.2.3 Transformed and Derived Parameters

The transformations used for this analysis were $\log_{10}$, square root, square and cube for the meteorologic and physiographic parameters. The derived parameters used in this analysis are defined below:

1. *Shape Factor* 1, $SF1 = \frac{DA}{LNTH^2}$

2. *Shape Factor* 2, $SF2 = \frac{DA}{LNTH}$

3. *Shape Factor* 3, $SF3 = DA * SLP * \frac{LNTH}{2}$

4. Infiltration or Recharge or Deep Percolation, INF = MAP-MAR-EVA

5. $P1 = (LNTH / \sqrt{SLP})^{1/2}$

6. $P2 = (BFI / (LNTH / \sqrt{SLP})^{1/2}$

The derived parameters SF1, SF2, SF3 and INF were newly defined specifically for this investigation.

5.2.4 Simple Correlation of Parameters

Simple correlations between independent parameters and between independent and dependent parameters were examined to screen parameters for input to subsequent regression analyses. The matrices of simple correlation coefficients for the Central, Southeastern and combined regions are presented in Appendix F. A significant correlation coefficient for a 95% level of significance has a magnitude equal or greater than 0.282, 0.388 and 0.226 for each of the Central, Southeastern and combined regions respectively. It is evident from the tables that a few parameters exhibit significant intercorrelation.

In general it was found that the Regulation Code (RN) is not significantly correlated with the low flows except for the Central region for $7Q_{20}$ and the magnitude of the correlation coefficient there also is small.

It was also found that the independent parameters which are generally most highly correlated to the dependent parameters are DA, EVA and BFI. (Some other parameters were found to be inter-correlated with these.) Some additional data transforms were undertaken (see Appendix A) which indicated that the cube of the drainage area remained highly correlated with the dependent parameters.

5.2.5 Regression Equation Development

A large number (several hundred) preliminary regression equations were developed in order to predict the $7Q_2$ and $7Q_{20}$ low flows as a function of basin physiographic and hydrometeorologic parameters (the procedure is described in Appendix A).

The final form of the equations developed are summarized in Tables 5.1 and 5.2. The final form of equation selected takes into account the prediction robustness assessed during testing on the reserved stations (see Appendix A).

A suitable level of accuracy for the Southeastern region could not be achieved without inclusion of the cube of drainage area as an independent parameter. This leads to a small regression coefficient (a_1), and while this is undesirable from a practical applications viewpoint, such coefficients were found to be statistically valid. Nevertheless, in our opinion, additional research is required to confirm that the Southeastern Region is unusual with respect to low flows and to investigate possible alternative forms of the prediction equation.

In addition, through analysis of interim results, it was noted that the Central and Southeastern regions were distinct regions with regard to their low flow characteristic interrelationships with the physiographic and climatic parameters. This confirms that it is not appropriate to analyse them as combined regions for the regression technique.

TABLE 5.1

SUMMARY OF REGRESSION ANALYSIS (CENTRAL REGION)

Y=a0+a1*DA+a2*BFI

Dependent Parameter	Independent Parameters					
	a0	a1	a2	N	SE	R^2
Central Region						
7Q20	-0.2134	6.6184E-04	0.7022	48	0.29	0.53
7Q2	-0.7216	1.8060E-03	1.7386	48	0.73	0.55
3Q2	-0.5398	1.6260E-03	1.2856	48	0.45	0.70
3Q20	-0.1841	5.8893E-04	0.6295	48	0.27	0.51
3Q50	-0.1331	4.5199E-04	0.5160	48	0.25	0.42
30Q2	-0.7119	2.2380E-03	1.6806	48	0.63	0.70
30Q20	-0.3275	9.7749E-04	0.9305	48	0.36	0.59
30Q50	-0.2839	8.7086E-04	0.8045	48	0.33	0.57

TABLE 5.2

SUMMARY OF REGRESSION ANALYSIS (SOUTHEASTERN REGION)

Y=a0+a1*DA^3+a2*BFI

Dependent Parameter	Independent Parameters					
	a0	a1	a2	N	SE	R^2
Southeastern Region						
7Q20	-0.5084	7.6323E-11	1.1460	25	0.64	0.88
7Q2	-0.9018	1.3049E-10	2.2728	25	0.98	0.91
3Q2	-1.0351	1.2409E-10	2.3828	25	0.93	0.91
3Q20	-0.6133	7.0980E-11	1.2527	25	0.64	0.89
3Q50	-0.6226	6.5153E-11	1.2372	25	0.64	0.85
30Q2	-1.0195	1.4637E-10	2.6144	25	1.03	0.92
30Q20	-0.5196	8.5495E-11	1.3062	25	0.74	0.88
30Q50	-0.4643	7.9836E-11	1.1773	25	0.70	0.87

5.3 Index Method

The regression analysis confirmed the conclusions drawn from the literature survey that drainage area (DA) is a good predictor of low flows. Therefore, a simple method using DA alone to estimate low flows was investigated. To meet this objective, graphs of $7Q_2$ and $7Q_{20}$ as a function of DA are plotted on Figure 5.1 for the Central, Southeastern and the combined region. A best fit analysis was performed and results of the regression are summarized in Table 5.3.

The ratios of 7Qy to various n day flows with y year recurrence were determined and plotted on Figure 5.2. Finally, the ratio of 7Qy to $7Q_2$ for all these regions was determined as shown on Figure 5.3.

To use this method knowing the drainage area, the $7Q_2$ flow is estimated from Figure 5.1 (or equation in Table 5.4) for the appropriate region in which the ungauged watershed is located. The 7Qy flow can then be estimated using Figure 5.2 for the required recurrence interval (y). Low flows for other n day durations can then be estimated using Figure 5.3.

The graphs of n-day low flows to 7 day low flows as well as the graph of 7 day y year recurrence ratio to $7Q_2$ low flows give some insight into the interrelationships between the various extreme value low flows. For example, the ratio of 7 day average low flows to 30 day low flows tends to decrease slightly with increased recurrence interval while the ratio of 7 day average low flows to 3 day average low flows increases with increased recurrence interval. As expected, the 30 day low flows are greater than 7 day low flows (i.e. ratio ranges from 1.1 to 1.3 times, 1.5 to 1.9 times, and 1.3 to 1.4 times the 7 day low flow values for the Central, Southeastern and combined regions).

The development and use of the Index Method indicates that it may be possible to utilize short periods of record to estimate $7Q_2$ flows and then use the other graphs developed here to estimate low flows for other recurrence intervals (i.e. a few years of data may provide a reasonable estimate of $7Q_2$ which can then be extended by use of the graphs).

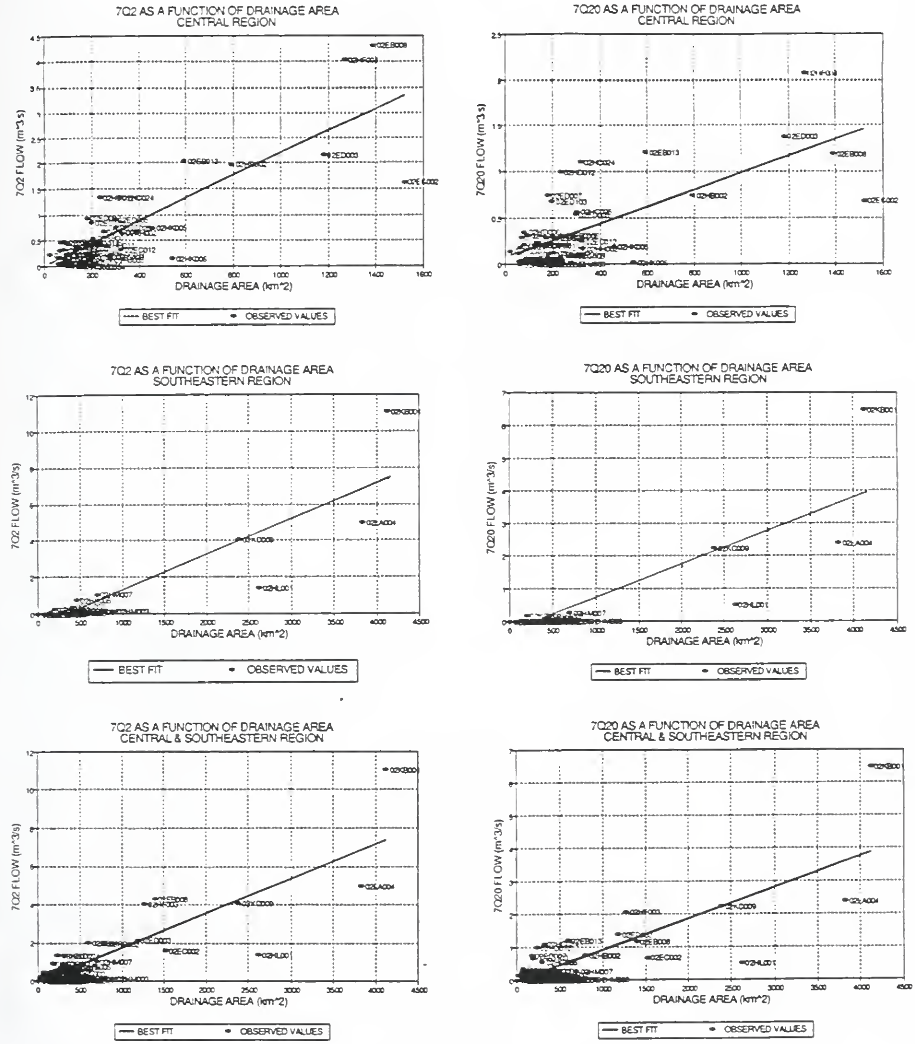
TABLE 5.3

SUMMARY OF BEST FIT ANALYSIS

FOR $7Q_2$ AND $7Q_{20}$ AS A FUNCTION OF DRAINAGE AREA

$Y = A_0 + A_1 * DA$

Dependent Parameter	Independent Parameters				
	a_0	a_1	N	SE	R^2
Central Region					
$7Q_{20}$	0.209	$5.89*10^{-4}$	48	0.35	0.46
$7Q_2$	0.383	$1.61*10^{-3}$	48	1.11	0.38
Southeastern Region					
$7Q_{20}$	-1.008	$1.46*10^{-3}$	25	1.371	0.7
$7Q_2$	-1.60	$2.51*10^{-3}$	25	2.182	0.73
Combined Central and Southeastern Regions					
$7Q_{20}$	-0.198	$1.180*10^{-4}$	73	0.98	0.71
$7Q_2$	0.118	$2.05*10^{-3}$	73	1.72	0.71



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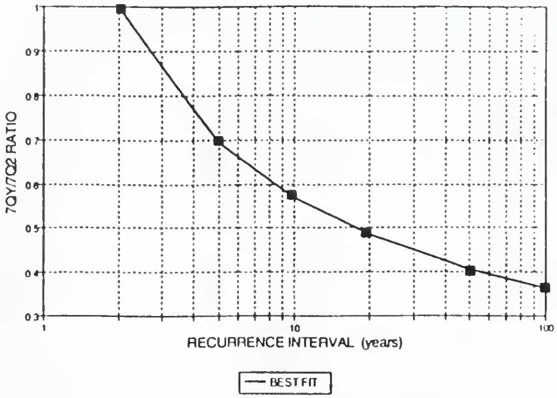
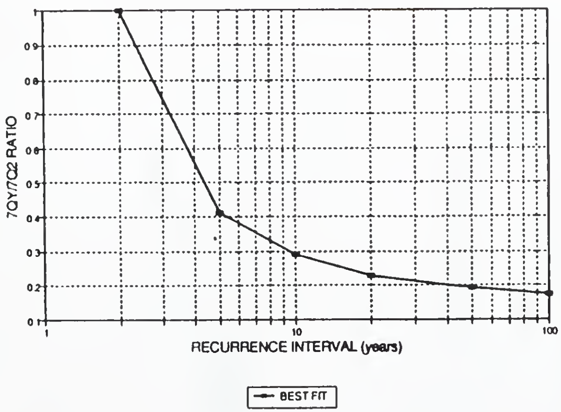
LOW FLOW AS A FUNCTION OF DRAINAGE AREA

FIGURE 5.1

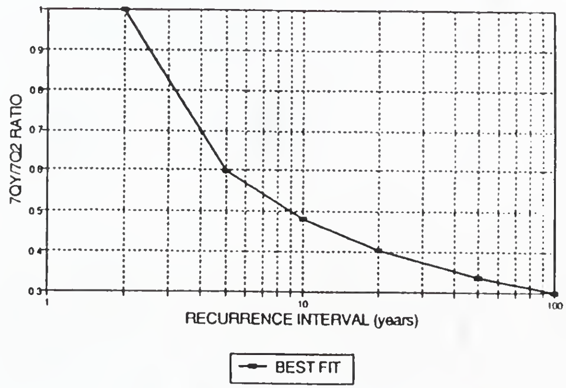
7QY/7Q2 RATIO AS A FUNCTION OF
RECURRENCE INTERVALS, CENTRAL REGION



7QY/7Q2 RATIO AS A FUNCTION OF
RECURRENCE INTERVAL SOUTHEASTERN REGION



7QY/7Q2 RATIO AS A FUNCTION OF
RECURRENCE INTERVALS CEN & SE REGION



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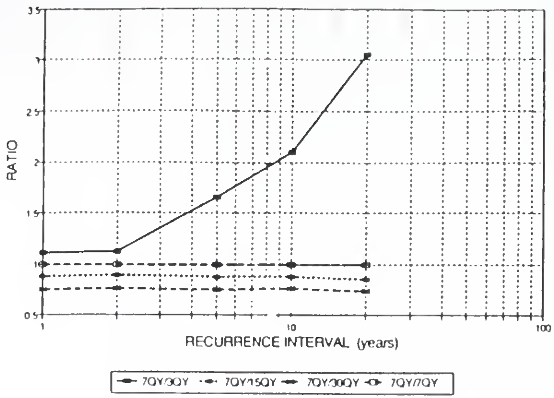
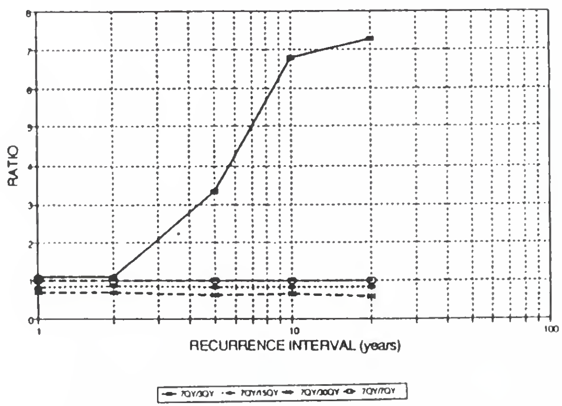
Ratios of $7Q_y/7Q_2$ as a Function of Recurrence Intervals

Figure 5.2

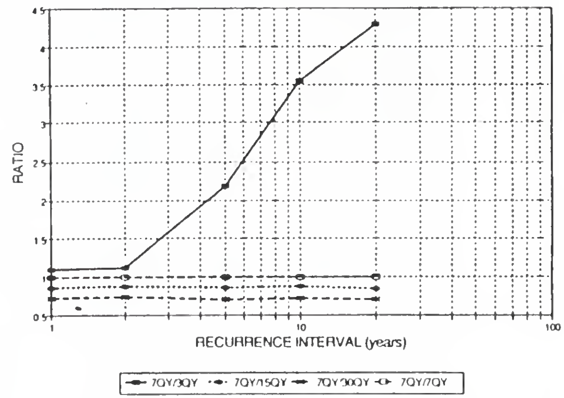
N-DAY DURATION RATIOS AS A FUNCTION OF
RECURRENCE INTERVAL CENTRAL REGION



N-DAY DURATION RATIOS AS A FUNCTION OF
RECURRENCE INTERVAL SOUTHEASTERN REGION



N-DAY DURATION RATIOS AS A FUNCTION OF
RECURRENCE INTERVAL CEN & SE REGION



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N-day Duration Ratios as a Function of Recurrence Interval

Figure 5.3

5.4 Mapped Isoline Method

Previous studies have used interrelationships between mapped isolines of BFI which had been converted to relate to unit area low flow characteristics (Cumming Cockburn Limited, 1989). Further to the previous analysis, isolines of unit area $7Q_2$ low flows were drawn for the Central and Southeastern combined regions (see Figures 5.3 a, b, c and d) (in pocket) using digital terrain modelling procedures.

First, a data set of station locations (x and y) and unit area low flow characteristics (i.e. 2 = $7Q_2$) were compiled. Then the data set was used by the GWN digital terrain modelling package to create a triangulation matrix over the region on which to interpolate the location of "even values" isoline intersection points. The isolines are then created based on the above interpolation.

The density of isolines is a reflection of station density. The higher density in the Central region results in closely packed isolines while the Southeastern region isolines are more spread out due to lower station density.

Several patterns seem to become evident using this procedure. For example, there appears to be some kind of lake effect which influences islines near Lake Ontario and some influence of the Canadian Shield on isolines in proximity to the Shield.

In addition, a map of unit area $7Q_{20}$ isolines was produced for the combined regions. As expected, the map has the same general appearance as the individual region $7Q_2$ isoline maps. However, in general, there are fewer stations and more stations had $7Q_{20} = 0$ in the SE region. Therefore, $7Q_2$ isolines were considered more appropriate and, for this study, further investigations used only the unit area $7Q_2$ mapped isolines. Future investigations should consider using the 7 day mean low flow as an index value and calculating this value for stations with short term records (e.g. 5 years) in order to refine the $7Q_2$ isoline maps in Southeastern Ontario.

Utilizing the combined map provides isolines based on a greater number of data points which provide better overall results.

5.5 Station Proration

In the past it has been common practice to prorate unit flows from nearby gauged watersheds. This is generally done by experienced hydrologists who have a good understanding of local stream characteristics and other factors within the region (i.e. diversions and regulation, etc.).

For assessment of this method, the $7Q_{20}$ low flow characteristics were determined for stations in the region and summarized in Figures 3.1 and 3.2 (in pocket).

To estimate low flows at a location between two or more sites located on Figures 3.1 and 3.2, the reciprocal distance percentage is used in the proration (i.e. the distance to nearby gauges would be estimated and unit values are then weighted by the reciprocal of the distance as a percentage and then averaged).

5.6 Summary

Of the above four low flow estimating methods described in the previous sections, Mapped Isolines and the Index Method are the easiest to use. The Station Proration Method has been included due to its widespread use and to evaluate whether the alternate techniques provide improved estimation of low flow characteristics. The relative prediction accuracy of all these methods is evaluated and discussed in Section 6.0.

6.0 TESTING PREDICTION METHODS

6.1 General

The relative prediction accuracy of the four methods developed in Section 5.0 was examined using 12, 9 and 21 stations for the Central, Southeastern and the combined regions, respectively. These stations were not included in the development of the regional low flow estimation techniques.

6.2 History of Test Stations

The test stations all have at least 10 years of record, and are active within the last 5 years. Stations were selected spatially to cover the complete region and with a range of similar characteristics to the remaining data base. The data base for these stations is presented in Tables 6.1 and 6.2 for the Central and Southeastern regions, respectively.

Further investigation indicated that two stations, 02KC014 and 02LB013 are heavily regulated such that low flows may be affected. For the Southeastern and hence, the combined Central and Southeastern regions, the analysis was conducted by including stations 02KC014 (Indian River near Pembroke) and 02LB013 (South Nation River at Casselman) in the test stations and also by excluding these two stations from the test stations.

6.3 Goodness of Fit

To test the goodness of fit, Cumming Cockburn Limited (1990) used the Nash-Sutcliffe (1970) model efficiency (N.S.R.^{2}). The N.S.R.^{2} is calculated by the following relationship:

$$N.S.R.^2 = 1 - \frac{\Sigma\ (Q_s - Q_o)^2}{\Sigma\ (Q_o - Q_m)^2} \qquad (1)$$

where Q_o and Q_s are the observed and simulated discharges, and Q_m is the mean of the observed discharges.

TABLE 6.1

SUMMARY OF METEOROLOGIC AND PHYSIOGRAPHIC DATA

FOR THE TEST STATIONS

(CENTRAL REGION)

Station Number	River Name and Gauge Location	DA	MAP	MAS	MAR	EVA	B.F.I.	SLP	Length (km)	GW(M)	ACLS (%)	RN	YRS	7Q20	7Q2
02EB004	NORTH BRANCH MUSKOKA RIVER AT PORT S	1390.0	990	290	538	690	0.620	0.041	78.75	0.914	100.0	1	17	1.459	4.508
02EC010	SCHOMBERG RIVER NEAR SCHOMBERG	42.9	810	230	223	805	0.350	3.123	14.00	0.366	5.0	0	16	0.013	0.020
02EC103	PEFFERLAW BROOK NEAR UDORA	332.0	850	220	307	785	0.570	1.044	32.00	0.671	6.0	0	13	0.718	0.865
02ED010	WILLOW CREEK AT MIDHURST	127.0	900	280	302	765	0.490	0.457	19.00	0.152	92.0	0	10	0.033	0.066
02ED102	BOYNE RIVER AT EARL ROWE PARK	211.0	840	250	305	795	0.530	5.242	43.00	0.390	0.0	0	14	0.388	0.465
02HB004	EAST OAKVILLE CREEK NEAR OMAGH	199.0	790	130	245	825	0.260	2.650	34.05	0.549	0.0	1	26	0.005	0.077
02HB012	GRINDSTONE CREEK NEAR ALDERSHOT	82.6	790	140	348	845	0.450	2.314	14.00	0.366	5.0	0	11	0.041	0.066
02HC003	HUMBER RIVER AT WESTON	800.0	790	150	225	818	0.450	1.684	58.00	0.183	3.0	1	31	0.546	1.032
02HC009	EAST HUMBER RIVER NEAR PINE GROVE	197.0	780	160	185	810	0.440	2.409	51.00	0.457	14.0	0	29	0.080	0.157
02HD004	NORTH WEST GANARASKA RIVER NEAR OSA	42.7	800	140	357	790	0.650	9.156	10.50	0.488	0.0	1	28	0.134	0.197
02HD008	OSHAWA CREEK AT OSHAWA	95.8	810	140	377	790	0.570	7.319	13.25	0.488	2.0	0	27	0.288	0.432
02HH001	EELS CREEK BELOW APSLEY	241.0	900	180	455	750	0.640	3.238	40.00	0.549	0.0	1	20	0.324	0.665

(SOUTHEASTERN REGION)

Station Number	River Name and Gauge Location	DA	MAP	MAS	MAR	EVA	B.F.I. (%)	SLP	Length (km)	GW(M)	ACLS (%)	RN	YRS	7Q20 Qo	7Q2 Qo
02HE001	BLOOMFIELD CREEK AT BLOOMFIELD	13.9	850	170	390	790	0.480	2.487	5.50	2.134	0.0	0	13	0.004	0.010
02HK003	CROWE RIVER AT MARMORA	1990.0	810	180	363	775	0.660	1.253	76.00	1.158	99.0	1	20	0.823	1.680
02HL004	SKOOTAMATTA RIVER NEAR ACTINOLITE	712.0	850	170	368	770	0.670	2.472	67.00	2.743	55.0	0	18	0.064	0.357
02HL005	MOIRA RIVER NEAR DELORO	308.0	850	170	374	770	0.530	1.710	53.25	2.743	17.0	0	17	0.007	0.036
02HM004	WILTON CREEK NEAR NAPANEE	112.0	890	180	407	780	0.370	1.079	34.50	4.267	12.0	0	11	0.006	0.026
02KC014	INDIAN RIVER NEAR PEMBROKE	443.0	800	190	344	680	0.610	1.155	40.00	0.305	10.0	0	14	0.280	0.481
02KF010	CLYDE RIVER NEAR LANARK	614.0	800	200	382	740	0.630	1.233	60.50	1.067	24.0	1	12	0.059	0.277
02LB007	SOUTH NATION RIVER AT SPENCERVILLE	246.0	850	190	392	750	0.390	0.436	28.00	0.610	96.0	0	35	0.000	0.016
02LB013	SOUTH NATION RIVER AT CASSELMAN	2410.0	800	200	460	735	0.300	0.353	108.00	2.134	0.0	1	12	0.097	0.529

The "observed" low flows ($7Q_2$ and $7Q_{20}$) were determined by undertaking a single station low flow frequency analysis for each of the stations listed in Table 6.1. Each prediction method was then utilized in turn to provide a simulated discharge. Graphical and statistical (N.S.R.^{2}) comparisons were then made for each method as discussed in Section 6.4.

6.4 Testing Estimation Methods

6.4.1 Testing of Regression Method

The preliminary regression equations developed in Section 5.2.5 were tested for prediction accuracy using the test stations. Based on these equations $7Q_2$ and $7Q_{20}$ low flows were estimated for the test stations. The details of testing are presented in Appendix A.

i) Central Region

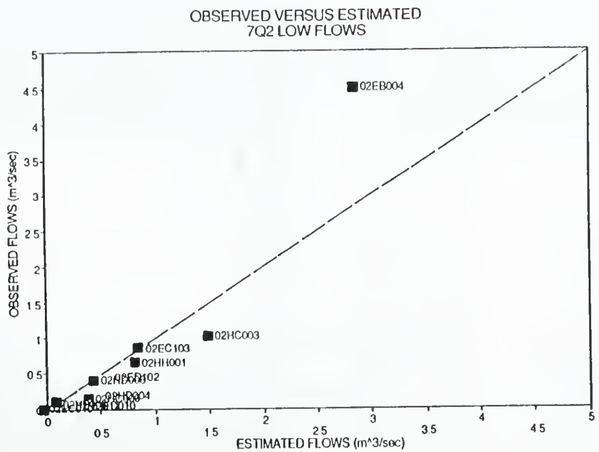
A comparison of the observed and estimated low flows by these regression equations is shown in Figures 6.1(a) and 6.1(b) for $7Q_2$ and $7Q_{20}$, respectively, along with a 45° line, on which all the points should lie for perfect simulation. An examination of these figures indicates that except for a few stations, the estimated flows are reasonable with an acceptable Nash-Sutcliffe statistic (see Table 6.2).

ii) Southeastern Region

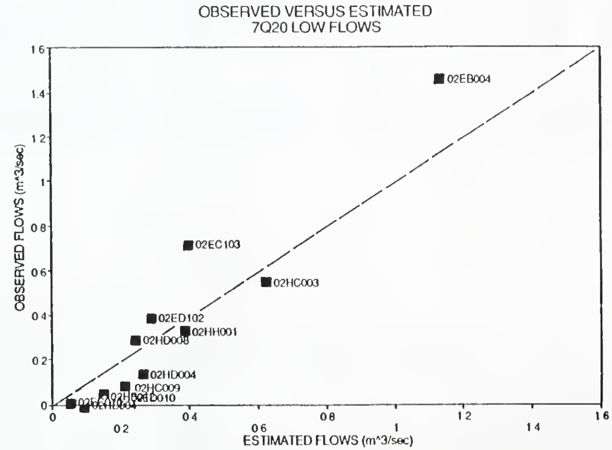
A comparison of the observed and estimated low flows by these regression equations is shown in Figures 6.2(a) and 6.2(b) for $7Q_2$ and $7Q_{20}$, respectively. These figures indicate an unsatisfactory prediction for $7Q_2$ but satisfactory prediction for $7Q_{20}$ if the two outlier stations are excluded (see Table 6.2 for the Nash-Sutcliffe statistics).

The regression equations were generally found to overestimae both the $7Q_2$ and $7Q_{20}$ low flows for most of the stations where the estimation is poor.

OBSERVED VERSUS ESTIMATED
7Q2 LOW FLOWS

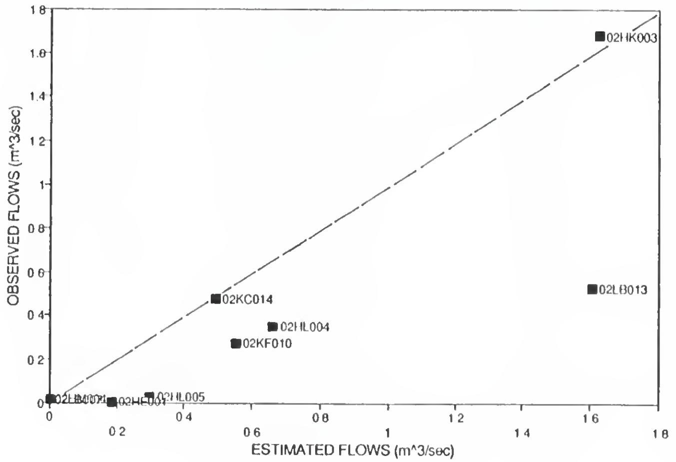


(a)



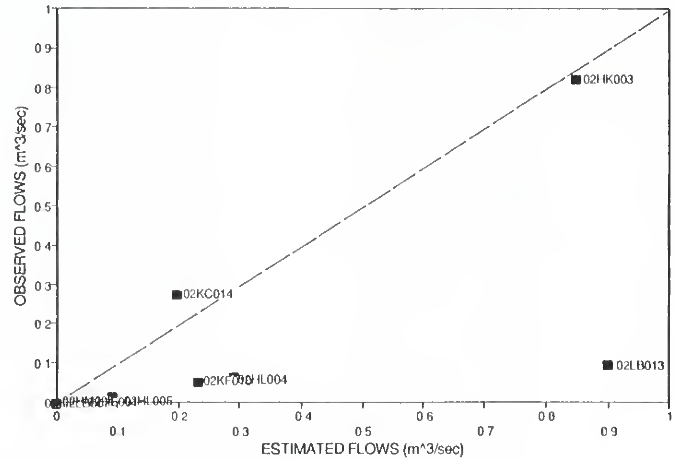
(b)

OBSERVED VERSUS ESTIMATED
7Q2 LOW FLOWS



(a)

OBSERVED VERSUS ESTIMATED
7Q20 LOW FLOWS



(b)

Cumming Cockburn Limited Consulting Engineers and Planners	Regional Low Flow Analysis Central & Southeastern Ontario	Observed versus Estimated Low Flows by Regression 7268 Southeastern Region Figure 6·2

iii) Discussion of Results

After a great deal of effort and trying various transformations and derived forms of various parameters, it has been found that the regression method can lead to satisfactory estimation of low flows in the Central region only. In the Southeastern region, the method gives unsatisfactory estimation of $7Q_2$ and $7Q_{20}$ low flows. The development of a regression prediction equation for the combined regions did not prove to be feasible. Results of the testing are summarized in Table 6.2.

6.4.2 Testing of Index Method

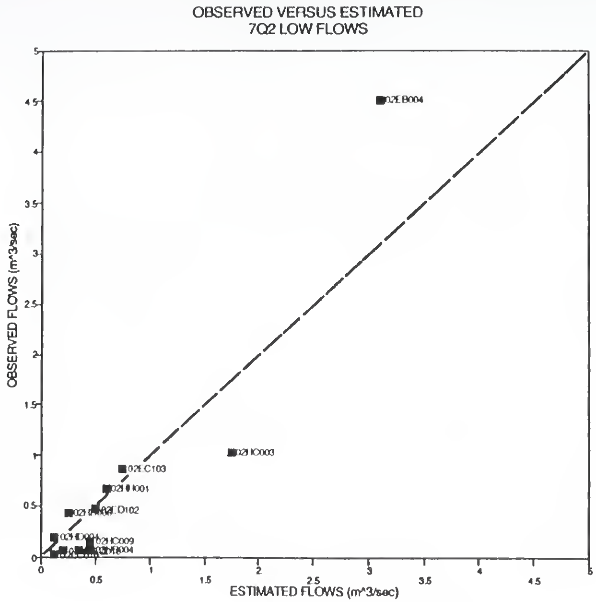
The $7Q_2$ low flows for the Central, Southeastern and the combined regions are estimated from Figure 5.1 using the drainage area of the respective station. The $7Q_{20}$ low flows for all these regions are estimated by multiplying the $7Q_2$ values by the ratio of $7Q_{20}/7Q_2$ derived from the appropriate figures for the Central, Southeastern and combined regions. The observed and estimated low flows along with the calculation of N.S.R.^{2} for these regions is presented in Appendix B. The observed and simulated $7Q_2$ and $7Q_{20}$ for the Central, Southeastern and combined regions are presented in Figures 6.3, 6.4 and 6.5 respectively.

i) Central Region

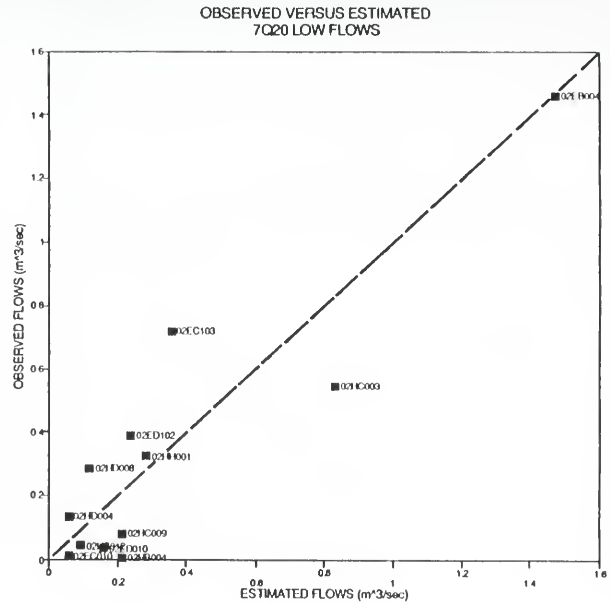
Reference to Figure 6.3 will indicate a reasonable comparison of observed and estimated low flows for $7Q_2$ and $7Q_{20}$. The Nash-Sutcliffe statistic (see Table 6.3) is also acceptable.

ii) Southeastern Region

An examination of Figure 6.4 indicates that for $7Q_2$, the flow is overpredicted for most of the test stations. For $7Q_{20}$, the flow is also overpredicted for a majority of the stations but is slightly underpredicted for 02HK003, Crowe River at Marmora and 02KC014, Indian River near Pembroke. Station 02HK003 is regulated with a drainage area of 1990 km^2. When stations 02KC014 and 02LB013 were excluded from the testing, the N.S.R.^{2} for $7Q_{20}$, improved substantially (see Table 6.2).

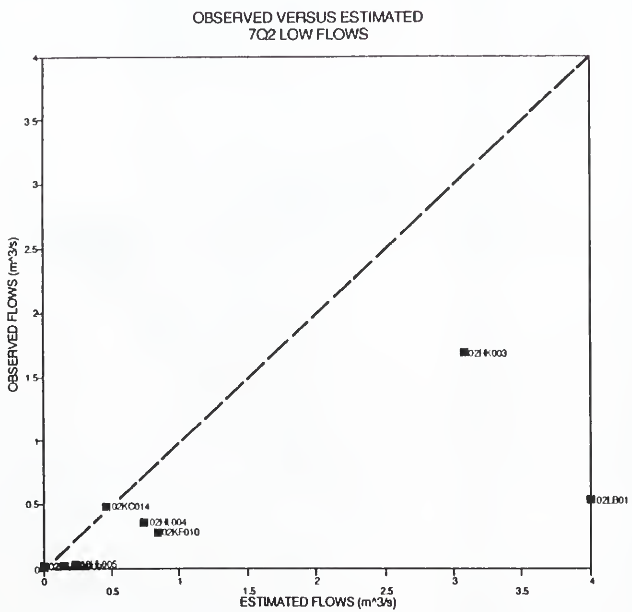


(a)

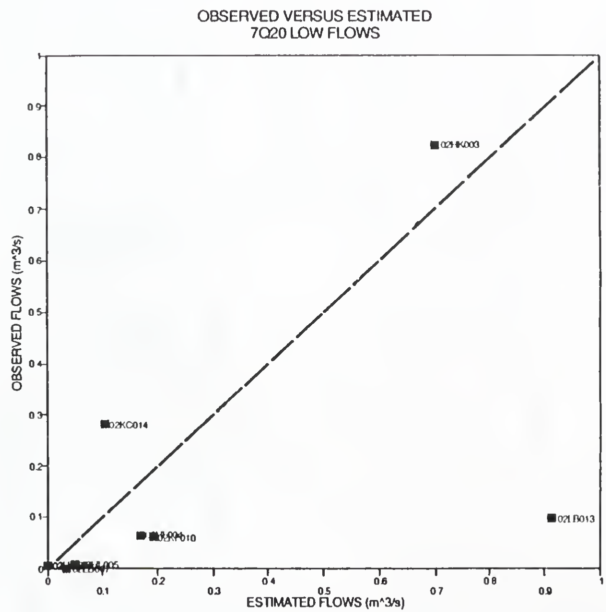


(b)

Cumming Cockburn Limited Consulting Engineers and Planners	Regional Low Flow Analysis Central & Southeastern Ontario	Observed versus Estimated Low Flows by Index Method Central Region 7268 Figure 6·3



(a)



(b)

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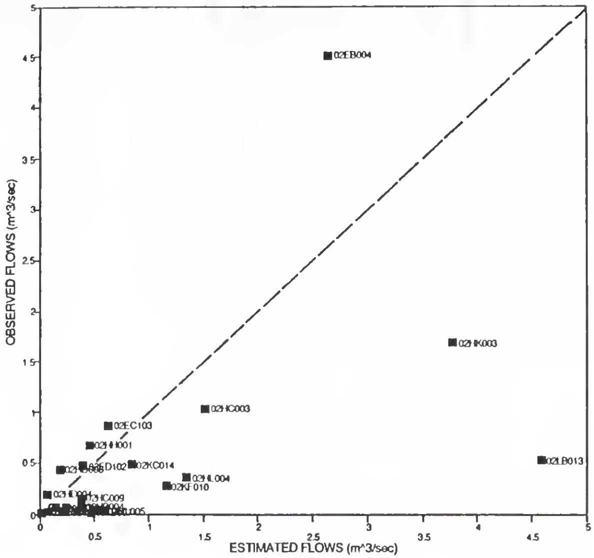
Regional Low Flow Analysis
Central & Southeastern Ontario

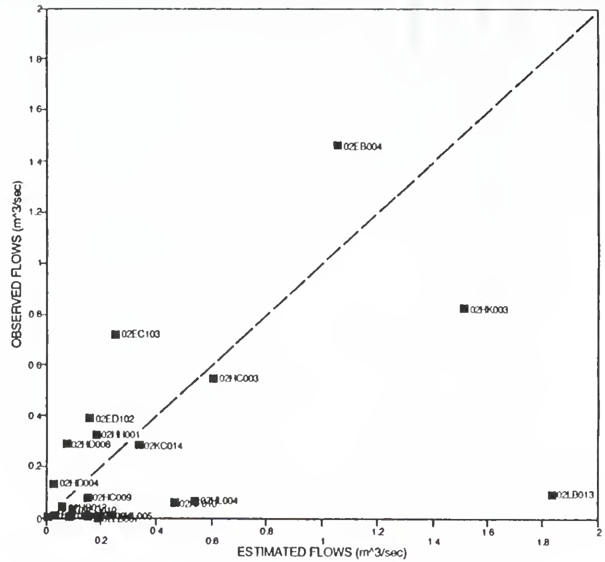
Observed versus Estimated
Low Flows by Index Method
Southeastern Region

OBSERVED VERSUS ESTIMATED
7Q2 LOW FLOWS



(a)

OBSERVED VERSUS ESTIMATED
7Q20 LOW FLOWS



(b)

Cumming Cockburn Limited Consulting Engineers and Planners	Regional Low Flow Analysis Central & Southeastern Ontario	Observed versus Estimated Low Flows by Index Method Combined Central & Southeastern Regions 7268 Figure 6

iii) Combined Regions

The results for the combined regions indicate that the pattern of estimation for almost all the stations is the same for $7Q_{20}$ and $7Q_2$. Even though the Southeastern region has fewer test (and development) stations combining the two regions has not resulted in any significant improvement in test results of the combined regions over the Southeastern region alone. When stations 02KC014 and 02LB013 were excluded from the analysis, the N.S.R.^{2} for $7Q_{20}$ increased substantially (see Table 6.2).

iv) Discussion of Results

It may be generally concluded that the index method is an appropriate method for estimating $7Q_2$ and $7Q_{20}$ low flows for the Central region and $7Q_{20}$ in the Southeastern region. The method is somewhat less reliable for both $7Q_2$ and $7Q_{20}$ using the result of the combined regions. Although the number of test stations in the Southeastern region is fewer than the Central region, combining the two regions together did not improve the prediction accuracy for the combined region over the Southeastern region.

6.4.3 Testing of Isoline Method

The Isoline maps were developed for the observed unit area low flows of $7Q_2$ for the development stations of the Central, Southeastern and the combined region (see Figures 5.3 a, 5.3 b, 5.3 c and 5.3 d). The $7Q_2$ unit low flows were estimated for the test stations in the Central and Southeastern regions by interpolating the values between the contour lines. The $7Q_{20}$ low flows were then determined by multiplying the estimated $7Q_2$ and $7Q_{20}/7Q_2$ ratio determined from the appropriate figures for the Central, Southeastern and combined regions (i.e. ratios developed in Index Method). The data base for estimation of low flows and calculation of N.S.R.^{2} is presented in Appendix D. The results of this analysis are presented in Figures 6.6, 6.7 and 6.8 for the Central, Southeastern and combined regions, respectively. The N.S.R.^{2} for test stations by the Isoline method is presented in Table 6.2.

i) Central Region

The N.S.R.^{2} for $7Q_2$ and $7Q_{20}$ is 0.95 and 0.53, respectively, which is reflected in the results on Figures 6.6(a), and 6.6(b). The prediction of $7Q_2$ is excellent and of $7Q_{20}$ is fairly satisfactory.

ii) Southeastern Region

The N.S.R.^{2} for estimation of $7Q_2$ and $7Q_{20}$ is 0.66 and 0.72 respectively, when stations 02KC014 and 02LB013 are included in the analysis. These values are fairly satisfactory for the type of system being dealt with in this study. Figure 6.7(a) indicates that the prediction of $7Q_2$ low flow is satisfactory for most of the stations and a slightly overprediction for a few stations. For the $7Q_{20}$ low flow, Figure 6.7(b) indicates a satisfactory estimation for most of the stations except slightly underestimation for station 02HK003, Crowe River at Marmora. This is a regulated stream with 1990 km^2 drainage area. Exclusion of stations 02KC014 and 02LB013 from the testing improved N.S.R.^{2} for estimation of $7Q_2$ from 0.66 to 0.89.

iii) Combined Central and Southeastern Region

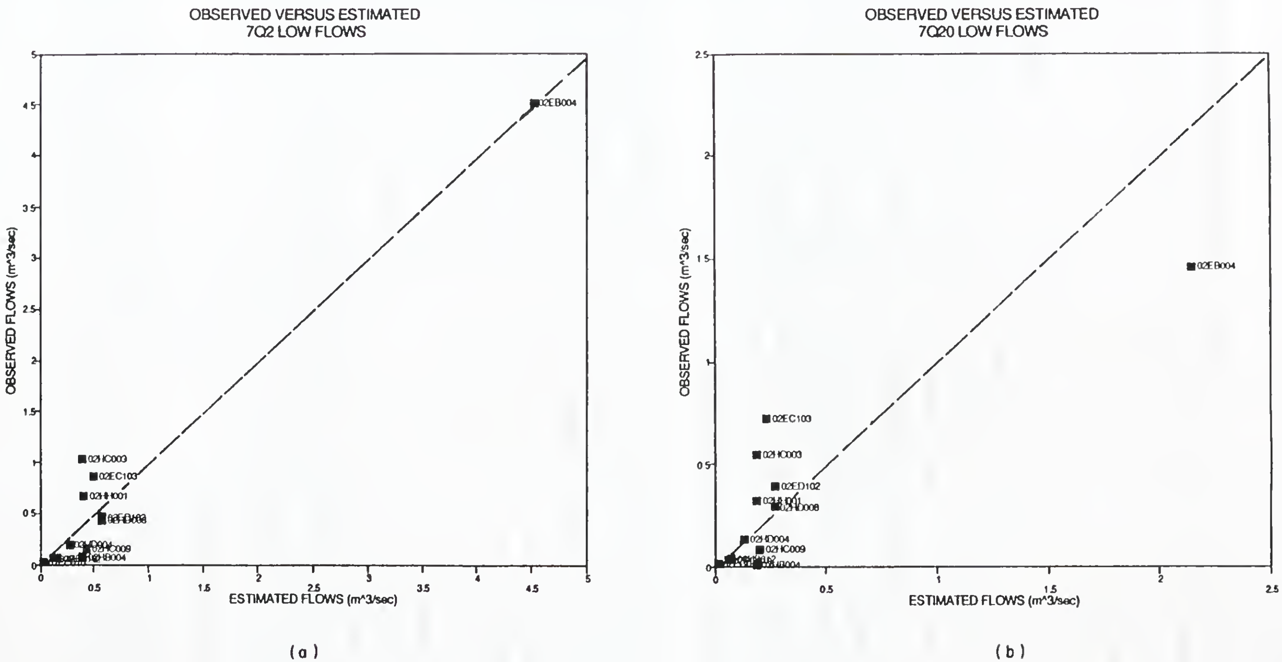
The N.S.R.^{2} for the combined region for $7Q_2$ and $7Q_{20}$ is 0.92 and 0.71 respectively, when stations 02KC014 and 02LB013 were included in the analysis, which indicates a satisfactory estimation of the low flows. Figure 6.8 indicates a good prediction of $7Q_2$ and a satisfactory estimation of $7Q_{20}$. The prediction accuracy slightly improved after exclusion of stations 02KC014 and 02LB013.

iv) Discussion of Results

It is generally concluded that the Isoline method was found to be the most consistent technique for satisfactorily simulating the $7Q_2$ and $7Q_{20}$ low flows for the Central, Southeastern and/or combined regions.

6.4.4 Testing of Station Proration Method

The method of reciprocal distance was used in the proration estimation, i.e. the distances from the test stations to nearby gauges were measured and the weighted average of the unit



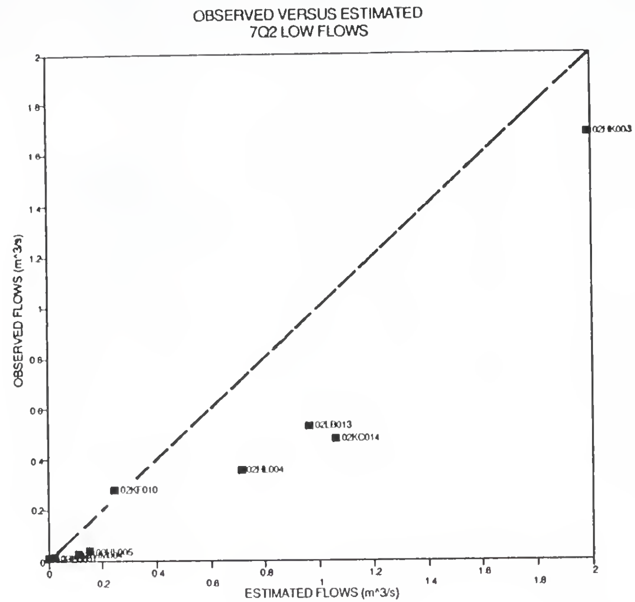
Cumming Cockburn Limited
Consulting Engineers and Planners

Regional Low Flow Analysis
Central & Southeastern Ontario

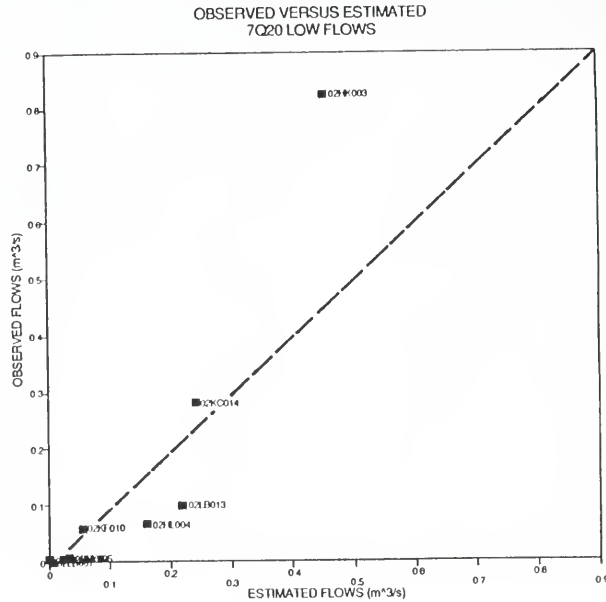
Observed versus Estimated
Low Flows by Isoline Method
Central Region

7268

Figure 6·6

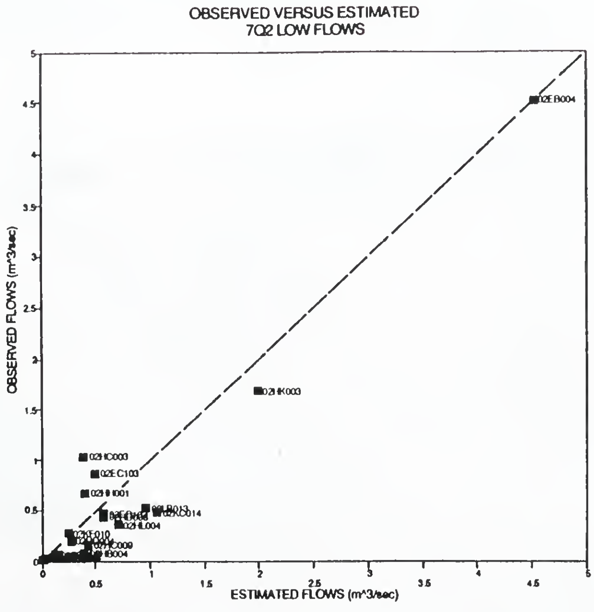


(a)

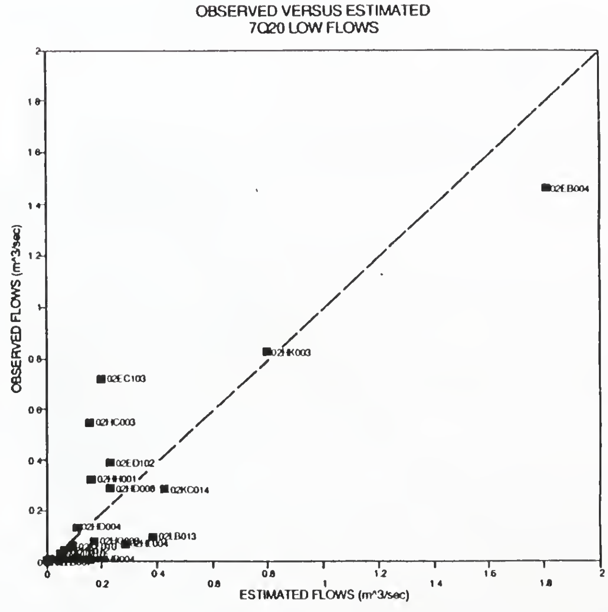


(b)

Cumming Cockburn Limited Consulting Engineers and Planners	Regional Low Flow Analysis Central & Southeastern Ontario	Observed versus Estimated Low Flows by Isoline Method Southeastern Region 7268 Figure 6·7



(a)



(b)

Cumming Cockburn Limited Consulting Engineers and Planners	Regional Low Flow Analysis Central & Southeastern Ontario	Observed versus Estimated Low Flows by Isoline Method Combined Central & Southeastern Regions

low flows was estimated for the test stations by using the reciprocal of distances to nearby stations and their observed unit area low flows. The figures from which these distances were measured and the tables presenting the data base for estimation of low flows and calculation of Nash-Sutcliffe R^2 are presented in Appendix C. The N.S.R.^{2} for estimation of $7Q_2$ and $7Q_{20}$ for the Central, Southeastern and combined regions are presented in Table 6.3. The results of this analysis for these regions are presented in Figures 6.9, 6.10 and 6.11.

i) Central Region

The prediction of $7Q_2$ low flow is satisfactory as is evidenced by Figure 6.9(a) while for $7Q_{20}$ the flow for 02EB004, North Branch Muskoka River at Port Sydney is overpredicted although within acceptable limits for all other stations. (Station 02EB004 is a regulated stream with a drainage area of 1390 km^2).

ii) Southeastern Region

An analysis of Figures 6.10(a) and 6.10(b) indicates that both the $7Q_2$ and $7Q_{20}$ low flows are overpredicted for almost all the stations except 02HK003, Crowe River at Marmora. The prediction for this region by this method is unsatisfactory for both the $7Q_2$ and $7Q_{20}$ low flows. The exclusion of stations 02KC014 and 02LK013 did not improve the result appreciably.

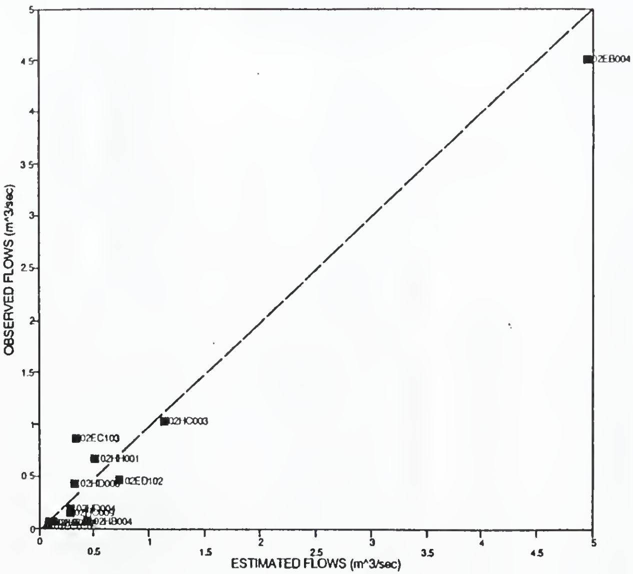
iii) Combined Central and Southeastern Regions

The N.S.R.^{2} for $7Q_2$ for the combined region is acceptable but not for $7Q_{20}$. An examination of Figures 6.11(a) and 6.11(b) indicates that the prediction for $7Q_2$ is satisfactory. However, for $7Q_{20}$, the results are not as good no matter if the analysis is conducted by including or excluding the stations 02KC014 and 02LK013.

6.5 Summary

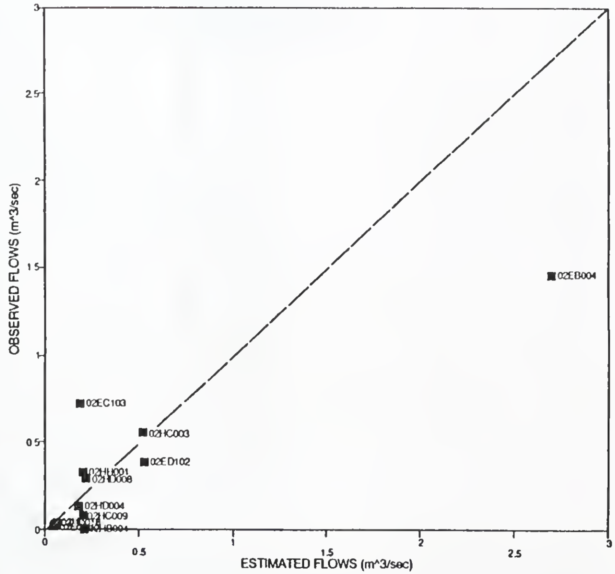
The Nash-Sutcliffe, R^2, for the test stations for all the regions and different methods of estimation of low flows is given in Table 6.2. The results are summarized below for each region.

OBSERVED VERSUS ESTIMATED
7Q2 LOW FLOWS



(a)

OBSERVED VERSUS ESTIMATED
7Q20 LOW FLOWS

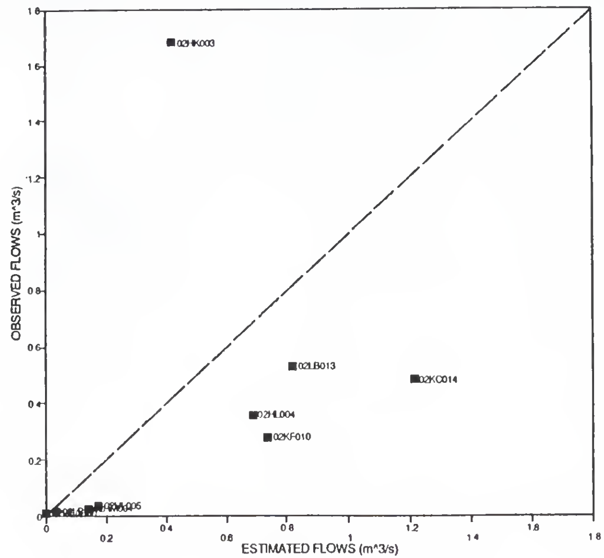


(b)

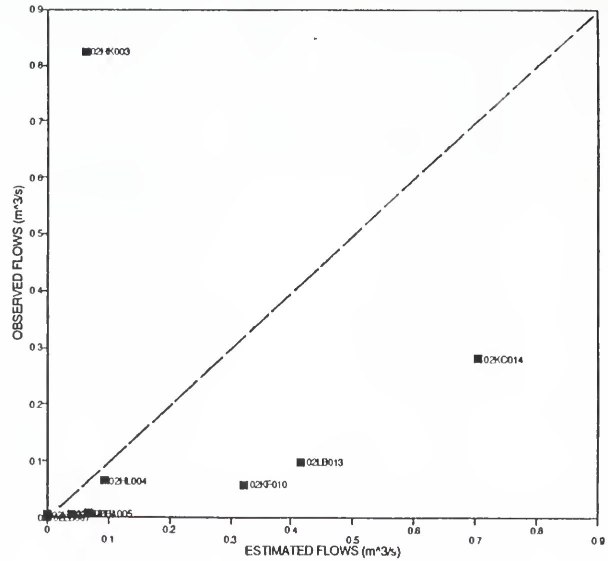
Cumming Cockburn Limited
Consulting Engineers and Planners

Regional Low Flow Analysis
Central & Southeast Ontario

Observed Versus Estimated Low Flows
by Station Proration,
Central Region

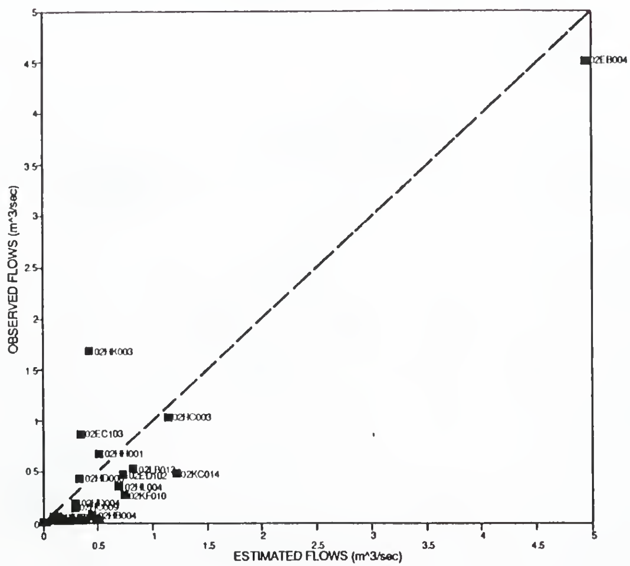


(a)

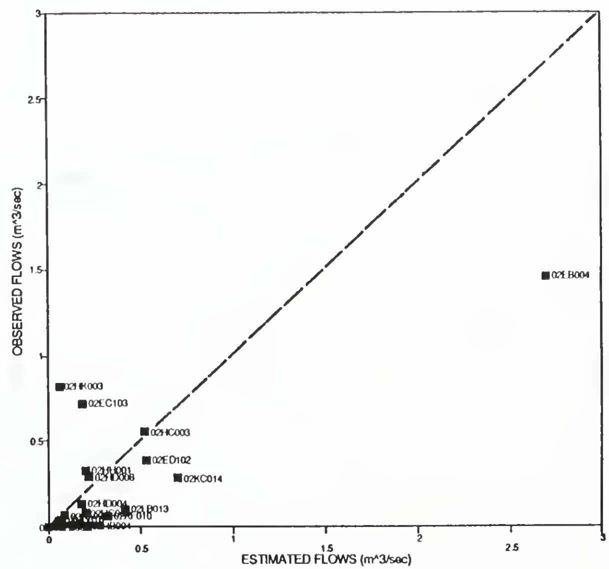


(b)

Cumming Cockburn Limited Consulting Engineers and Planners	Regional Low Flow Analysis Central & Southeast Ontario	Observed Versus Estimated Low Flows by Station Proration, Southeastern Region 7268 Figure 6.10



(a)



(b)

Cumming Cockburn Limited Consulting Engineers and Planners	Regional Low Flow Analysis Central & Southeastern Ontario	Observed versus Estimated Low Flows by Station Proration, Combined Central & Southeastern Regions

i) Central Region

The N.S.R.^{2} for estimation of $7Q_2$ is the highest (0.96) by the station proration method followed by the isoline method (0.95), index method (0.83) and the regression method 0.81). For $7Q_{20}$ the highest (0.84) is by the regression method followed by the index method (0.82), isoline method (0.53) and station proration (0.02). It is concluded that the index, regression or isoline methods may be used to estimate low flows with acceptable accuracy for this region.

ii) Southeastern Region

The N.S.R.^{2} for estimation of $7Q_2$ is the highest (0.89) for the Isoline method followed by regression (0.87), station proration (0.12) and Index method (-0.12), while for $7Q_{20}$ the highest (0.92) is by the Index method followed by Isoline method (0.73), regression (0.84) and station proration (-0.18). It is concluded that the Isoline method can satisfactorily simulate both $7Q_2$ and $7Q_{20}$ in this region. Since the $7Q_{20}$ low flows are estimated from the maps of $7Q_2$ and multiplying it by a $7Q_{20}/7Q_2$ ratio as described in the Index method, it can be anticipated that the other low flows can also be satisfactorily simulated by these methods.

iii) Combined Central and Southeastern Regions

The N.S.R.^{2} for estimation of $7Q_2$ is highest (0.95) by the Isoline method followed by station proration (0.86) and Index method (0.45). For $7Q_{20}$ the best result (0.75) is by the Isoline method, followed by the index method (0.44) and station proration (0.04). A satisfactory regression equation could not be produced when the regions were combined. Only the isoline method could satisfactorily estimate the low flows for the combined Central and Southeastern regions.

iv) Discussion of Results

For estimation of low flows in the Central region, any one of the index, regression or isoline could be used satisfactorily. On the other hand, for the Southeastern and the combined regions, only the isoline method produced consistent estimates of low flows. It is, therefore,

concluded that the isoline method is the most robust technique for estimating low flows in the Central and Southeastern regions.

It should be noted that all the estimation technqiues could not produce satisfactory results for some stations. Therefore, care should be taken when using these methodologies in estimating low flows for ungauged watersheds.

TABLE 6.2 (a)

THE NASH-SUTCLIFFE, R^2

FOR TESTING THE ESTIMATION TECHNIQUES*

Method/ Low Flows	Central Region	Southeastern Region	Combined Region
Regression Mehtod			
7q20	0.84	-0.30	N/A
7q2	0.81	0.36	N/A
Index Method			
7q20	0.82	-0.29	-0.67
7q2	0.83	-5.46	-0.38
Mapped Isolines Method			
7q20	0.53	0.72	0.71
7q2	0.95	0.66	0.92
Station Proration Method			
7q20	0.02	-0.63	-0.01
7q2	0.96	-0.14	0.83

* includes stations 02KC014 and 02LB013

N.S.R.^2=1 Represents Perfect Prediction

TABLE 6.2 (b)

THE NASH-SUTCLIFFE, R^2

FOR TESTING THE ESTIMATION TECHNIQUES**

Method/ Low Flows	Central Region	Southeastern Region	Combined Region
Regression Method			
7q20	0.84	0.84	N/A
7q2	0.81	0.87	N/A
Index Method			
7q20	0.82	0.92	0.44
7q2	0.83	-0.12	0.45
Mapped Isolines Method			
7q20	0.53	0.73	0.75
7q2	0.95	0.89	0.95
Station Proration Method			
7q20	0.02	-0.18	0.04
7q2	0.96	0.12	0.86

** excludes stations 02KC014 and 02LB013

7.0 CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

i) Central Region

a) For this region, any of the methods, i.e. Index, Regression or Mapped Isoline can be used for estimating low flows.

b) The regression equation developed is based on the parameters DA and BFI.

c) The regression equations based on these parameters were developed for the 3, 7 and 30 day low flows for recurrence intervals of 2, 20 and 50 years and presented in Table 5.4.

ii) Southeastern Region

a) Three of the estimation techniques (Regression, Index and Station Proration) did not provide consistently robust estimates of the $7Q_2$ and $7Q_{20}$ low flows. The Index method gave excellent prediction for $7Q_{20}$ but very poor for $7Q_2$. For the regression method, the equation based on DA^3 and BFI gave a satisfactory prediction for $7Q_2$ but unsatisfactory for $7Q_{20}$. It is concluded that none of these methods (Index, Regression or Station Proration) could satisfactorily simulate the low flows for this region.

b) The Mapped Isoline method provided the most consistently robust method for estimation of both the $7Q_2$ and $7Q_{20}$ low flows.

iii) Combined Central and Southeastern Regions

a) The Index Method resulted in fair estimation of low flows while the station proration method is not consistent in estimating both the $7Q_2$ and $7Q_{20}$ low flows, resulting in a satisfactory prediction for $7Q_2$ and poor for $7Q_{20}$. A satisfactory regression equation could not be produced for the combined regions.

b) The Mapped Isolines method gave good prediction for $7Q_2$ and $7Q_{20}$.

Overall, it was concluded that the Mapped Isoline Method was the most consistent for prediction of both the $7Q_2$ and $7Q_{20}$ low flows.

7.2 Recommendations

a) Isoline maps of unit area low flows should be prepared by digital terrain modelling using a Geographical Information System (GIS) for all the regions defined by the Ministry of the Environment.

b) Refinement of the regression technique for watersheds in the Southeastern region appears to require additional investigation including definition and incorporation of other watershed parameters in order to sufficiently explain low flow characteristics.

c) The regression studies suggest that the maximum fluctuation of the groundwater table may be an important parameter under certain conditions. The maximum fluctuations of the water table for a well was calculated from the observed maximum and minimum water table depths reported in the Environment Atlas of Observation Wells in Ontario published by the Ontario Ministry of the Environment, 1980. The data was old and only sparse well observation information was available, so it is recommended that the Atlas of the Observation Wells be updated and records for a larger number of observation wells should be obtained.

d) Statistical tests indicate that a large number of the stations data used in this study show; trend, dependence and some non-randomness characteristics. Future investigations should examine and quantify the extent of trends on low flow series.

e) The single station analysis was based on flow data up to 1986. Since 5 years of additional data for active stations, and because some additional stations record length may now qualify for reliable statistical analysis, we feel the single station data should be updated for future studies and regular analysis of gauge station data.

f) The techniques developed within this study do not always accurately depict low flows for all stations and, therefore, care is recommended by anyone applying these techniques.

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APPENDIX A
REGRESSION

A.1 Development of Regression Equations

Over 250 preliminary regression equations were developed in order to predict the $7Q_2$ and $7Q_{20}$ low flows as a function of hydrometeorologic and basin physiographic parameters, parameter transforms or derived transforms. Potential equations were evaluated based on various groups of parameters (see Table A.1).

Selected preliminary regression equations were developed and tested for estimation of the $7Q^2$ and $7Q_{20}$ low flows in the Central, Southeastern and combined regions.

On the basis of the highest value of Nash-Sutcliffe R^2, for the testing stations, to be described subsequently, the following groups of parameters were found to give the highest prediction accuracy:

Central Region:	DA and LOG_{10} EVA
Southeastern Region:	DA^3, BFI^2 and $LNTH^2$
Combined Regions:	DA^3, BFI^2 and $LNTH^2$

The coefficients of these parameters for different low flows are presented in Tables A.1, A.2 and A.3 for the Central, Southeastern and the combined region. These results are obtained when two stations, 02KC014 (Indian River near Pembroke) and 02LB013 (South Nation River near Casselman) were included in the test stations for the Southeastern region and hence in the combined region. When these stations were excluded, then for the combined region, the regression equation based on DA^3, BFI^3 and Log_{10} EVA gave the best estimation of both the $7Q_2$ and $7Q_{20}$. The coefficients of the regression equations based on these parameters for the combined region are given in Table A4.

Table A.1 Summary of Regression Analysis

Group	Region	Parameter/Transformed or Derived Form	Low Flow	N
Group I	CN	MAP, DA, LNTH, RN, GW, BFI, MAS, MAE, SLP, ACLS and MAR	7Q2	48
			7Q20	48
	SE		7Q2	25
			7Q20	25
	CNSE		7Q2	73
			7Q20	73
Group II				
First Set	CN	GW^3, RN, MAP, Log10 MAE, SLP^3, SF2 AND Log10 BFI	7Q2	48
		Log10 GW, RN, INF, MAS, SLP^2, SF2, BFI^3 and ACLS	7Q20	48
	SE	Log10 GW, RN, INF, SF3, BFI^3 and MAS	7Q2	25
		Log10 GW, RN, INF, SF3, BFI^3 and ACLS	7Q20	25
	CNSE	GW^3, RN, MAP^3, MAR^3, MAE, MAS^3, SF3, BFI^3 and ACLS	7Q2	73
		GW^3, RN, MAP^3, Log10 MAR, MAE^3, MAS^3, SF3 AND BFI^3	7Q20	73
Second Set	CN	GW^3, RN, MAP^3, MAS^3, Log10 MAR, SLP^3, EVA^3, DA^3, BFI^3, LNTH^3 and ACLS	7Q2	48
			7Q20	48
	SE		7Q2	25
			7Q20	25
	CNSE		7Q2	73
			7Q20	73
Third Set	CN	Log10 GW, RN, MAP^3, MAS^3, Log10 MAR, SLP^3, MAE^3, DA^3, BFI^3, LNTH^3 and ACLS	7Q2	48
			7Q20	48
	SE		7Q2	25
			7Q20	25
	CNSE		7Q2	73
			7Q20	73
Fourth Set	CN	GW^3, RN, MAP^3, MAS^3, Log10 MAR, SLP^3, Log10 MAE, DA^3, BFI^3, LNTH^3 and ACLS	7Q2	48
			7Q20	48
	SE		7Q2	25
			7Q20	25
	CNSE		7Q2	73
			7Q20	73
Fifth Set	CN	Log10 GW, RN, MAP^3, MAS^3, Log10 MAR, SLP^3, Log10 MAE, DA^3, BFI^3, LNTH^3 and ACLS	7Q2	48
			7Q20	48
	SE		7Q2	25
			7Q20	25
	CNSE		7Q2	73
			7Q20	73
Sixth Set	CN	Log10 MAS, Log10 MAR, DA^3, BFI^2 and LNTH^2	7Q2	48
			7Q20	48
	SE		7Q2	25
			7Q20	25
	CNSE		7Q2	73
			7Q20	73
Group III	CN	MAE and DA	7Q2	48
			7Q20	48
	SE	DA, MAE and BFI	7Q2	25
			7Q20	25
	CNSE	(a) DA, GW and MAE	7Q2	73
			7Q20	73
		(b) DA, BFI and MAE	7Q2	73
			7Q20	73
Group IV	CN	DA and Log10 MAE	7Q2	48
			7Q20	48
	SE	DA^3, MAE^3 and BFI^2	7Q2	25
			7Q20	25
	CNSE	(a) DA^3, Log10 MAE and Log10 GW	7Q2	73
			7Q20	73
		(b) DA^3, Log10 MAE and BFI^3	7Q2	73
			7Q20	73
Group V	CN	DA^3, BFI^2 and LNTH^2	7Q2	48
			7Q20	48
	SE		7Q2	25
			7Q20	25
	CNSE		7Q2	73
			7Q20	73
Group VI	CN	DA only	7Q2	48
			7Q20	48
	SE		7Q2	25
			7Q20	25
	CNSE		7Q2	73
			7Q20	73

N-Number of Stations SEE-Standard Error of Estimates

Table A-2 Summary of Regression Analysis (Central Region)

Y=a0+a1*DA+a2*LOG10 EVA

Dependent Parameter	Independent Parameters					
	a0	a1	a2	N	SE	R^2
7Q20	27.32	3.02*10^-4	-9.33	48	0.29	0.62
7Q2	130.24	2.39*10^-4	-44.69	48	0.624	0.8
3Q2	50.42	9.58*10^-4	-17.27	48	0.552	0.72
3Q20	22.51	2.94*10^-4	-7.68	48	0.266	0.6
3Q50	17.36	2.39*10^-4	-5.91	48	0.241	0.53
30Q2	75.7	1.24*10^-3	-25.95	48	0.764	0.72
30Q20	39.23	4.39*10^-4	-13.42	48	0.408	0.63
30Q50	33.48	4.03*10^-4	-11.45	48	0.374	0.61

Table A-3 Summary of Regression Analysis (South Eastern Region)

Y=a0+a1*DA^3+a2*BFI^2+a3*LNTH^2

Dependent Parameter	Independent Parameters						
	a0	a1	a2	a3	N	SE	R^2
7Q20	-0.529	7.31*10^-11	1.759	2.31*10^-5	48	0.91	0.87
7Q2	-0.78	1.24*10^-10	3.186	3.53*10^-5	48	1.37	0.89
3Q2	-0.95	1.24*10^-10	3.935	-2.45*10^-5	48	1.25	0.91
3Q20	-0.73	7.37*10^-11	2.668	-3.87*10^-5	48	0.84	0.88
3Q50	-0.78	6.86*10^-11	2.877	-5.01*10^-5	48	0.81	0.88
30Q2	-0.76	1.39*10^-10	3.289	4.74*10^-5	48	0.9	0.9
30Q20	-0.38	7.79*10^-11	1.102	7.68*10^-5	48	1.1	0.84
30Q50	-0.33	7.18*10^-11	0.869	8.31*10^-5	48	1.047	0.83

Table A-4 Summary of Regression Analysis (Combined Central and South Eastern Region)

Y=a0+a1*DA^3+a2*BFI^2+a3*LNTH^2

Dependent Parameter	Independent Parameters						
	a0	a1	a2	a3	N	SE	R^2
7Q20	-0.215	7.32*10^-11	1.887	-1.55*10^-5	73	0.649	0.87
7Q2	-0.666	1.16*10^-10	5.254	-5.80*10^-5	73	1.23	0.85
3Q2	-0.641	1.17*10^-10	4.393	-4.11*10^-5	73	0.98	0.9
3Q20	-0.287	7.25*10^-11	2.03	-3.46*10^-5	73	0.61	0.88
3Q50	-0.278	6.85*10^-11	1.785	-3.00*10^-5	73	0.58	0.88
30Q2	-0.688	1.28*10^-10	5.35	-2.33*10^-5	73	1.24	0.88
30Q20	-0.239	7.70*10^-11	2.38	-1.04*10^-5	73	0.81	0.84
30Q50	-0.206	7.19*10^-11	2.05	-3.29*10^-5	73	0.75	0.84

Table A-5 Summary of Regression Analysis (Combined Central and South Eastern Region)

Y=a0+a1*DA^3+a2*BFI^3+a3*LOG10 EVA

Dependent Parameter	Independent Parameters						
	a0	a1	a2	a3	N	SE	R^2
7Q20	40.08	6.35*10^-11	1.00	-13.82	73	0.57	0.90
7Q2	105.36	8.94*10^-11	2.69	-36.35	73	0.92	0.92
3Q2	62.29	9.73*10^-11	3.23	-21.55	73	0.83	0.93
3Q20	33.15	6.13*10^-11	1.26	-11.47	73	0.55	0.90
3Q50	28.46	5.86*10^-11	1.17	-9.86	73	0.53	0.90
30Q2	86.13	1.06*10^-10	3.79	-29.73	73	1.02	0.92
30Q20	53.64	6.55*10^-11	1.20	-18.48	73	0.69	0.89
30Q50	49.20	6.21*10^-11	1.00	-16.95	73	0.65	0.88

A.2 Testing of the Regression Equations

On the basis of the testing and development of the regression equations, engineering judgement and the practical utility of these equations, the following groups of parameters were found to have given the most satisfactory results:

Central Region:	DA and BFI
Southeastern Region:	DA^3 and BFI

It was found that no common regression equation could satisfactorily predict the low flows for both the regions. This indicated that the prediction of the low flows by regression should be carried out independently for each region.

The coefficients of those parameters for different low flows are presented in Tables 5.4 and 5.5 in the main text, for the Central and Southeastern regions, respectively. Since the prediction of low flows by regression method is not consistent with the development of regression equation for the Southeastern region as regards the accuracy of prediction is concerned, it was tried to simulate $7Q_{20}$ from $7Q_2$ and using the ratio of $7Q_{20}/7Q_2$ from Figure 5.2 as 0.228. The $7Q_2$ low flows were predicted by the regression equation. This method improved the accuracy of prediction of $7Q_{20}$ tremendously over the prediction of $7Q_{20}$ directly by regression equation.

Further investigations indicated that when two heavily regulated stations (02KC014 and 02LB013) were removed from the testing, the regression method produced satisfactory results for the $7Q_{20}$ estimates for the test stations in the Southeastern region.

TABLE A.6

SUMMARY OF FINAL REGRESSION ANALYSIS TESTING

Group	Parameters	NASH-SUTCLIFFE R^2			
		Region			
		Central		Southeastern	
III	EVA, DA, BFI and GW	0.71	0.72	-6.32	-15.49
IV	DA^3, BFI^2 and $LNTH^2$	0.28	0.4	-0.66	-0.51
V	DA	0.68	0.67	-7.35	-11.32
VI	SF2, MAP, MAR, EVA and BFI	0.82	0.78	-4.43	-6.81
VII	SF2 and BFI	0.65	0.72	-4.3	-6.8
IX	DA, LNTH and BFI	0.8	0.85	-7.3	-11.2
X	DA and BFI	0.81	0.84	-7.7	-11.9
XI	DA^2 and BFI	0.76	0.75	-1.4	-3.1
XII	$DA^{0.5}$ and BFI	0.77	0.84	-8.7	-16.1
XIII	DA^3 and BFI	0.68	0.67	0.36	-0.31

TABLE A.7

SUMMARY OF REGRESSION RESULTS, CENTRAL REGION

Station Number	River Name and Gauge Location	7Q20	(Qo-Qm)^2	R7Q20	(Qs-Qo)^2	7Q2	(Qo-Qm)^2	R7Q2	(Qs-Qo)^2
02EB004	NORTH BRANCH MUSKOKA RIVER AT PORT S	1.459	1.262	1.142	0.101	4.508	14.406	2.867	2.694
02EC010	SCHOMBERG RIVER NEAR SCHOMBERG	0.013	0.104	0.061	0.002	0.020	0.480	-0.036	0.003
02EC103	PEFFERLAW BROOK NEAR UDORA	0.718	0.146	0.407	0.097	0.865	0.023	0.869	0.000
02ED010	WILLOW CREEK AT MIDHURST	0.033	0.092	0.215	0.033	0.066	0.418	0.360	0.086
02ED102	BOYNE RIVER AT EARL ROWE PARK	0.388	0.003	0.298	0.008	0.465	0.061	0.581	0.013
02HB004	EAST OAKVILLE CREEK NEAR OMAGH	0.005	0.109	0.101	0.009	0.077	0.404	0.090	0.000
02HB012	GRINDSTONE CREEK NEAR ALDERSHOT	0.041	0.087	0.157	0.014	0.066	0.418	0.210	0.021
02HC003	HUMBER RIVER AT WESTON	0.546	0.044	0.632	0.007	1.032	0.102	1.506	0.224
02HC009	EAST HUMBER RIVER NEAR PINE GROVE	0.080	0.065	0.226	0.021	0.157	0.309	0.399	0.059
02HD004	NORTH WEST GANARASKA RIVER NEAR OSA	0.134	0.041	0.271	0.019	0.197	0.266	0.486	0.083
02HD008	OSHAWA CREEK AT OSHAWA	0.288	0.002	0.250	0.001	0.432	0.079	0.442	0.000
02HH001	EELS CREEK BELOW APSLEY	0.324	0.000	0.395	0.005	0.665	0.002	0.826	0.026
	AVG	0.336	0.163	0.346	0.026	0.713	1.414	0.717	0.267
	STD	0.404	0.334	0.281	0.033	1.189	3.921	0.757	0.734
	SUM	4.029	1.955	4.155	0.318	8.550	16.967	8.600	3.210
	N.S.R^2			0.838				0.811	

TABLE A.8

SUMMARY OF REGRESSION RESULTS, SOUTHEASTERN REGION

Station Number	River Name and Gauge Location	7Q20 Qo	(Qo-Qm)^2	R7Q20	(Qs-Qo)^2	7Q2 Qo	(Qo-Qm)^2	R7Q2	(Qs-Qo)^2
)2HE001	BLOOMFIELD CREEK AT BLOOMFIELD	0.004	0.021	0.042	0.001	0.010	0.136	0.189	0.032
)2HK003	CROWE RIVER AT MARMORA	0.823	0.454	0.849	0.001	1.680	1.692	1.627	0.003
)2HL004	SKOOTAMATTA RIVER NEAR ACTINOLITE	0.064	0.007	0.287	0.050	0.357	0.000	0.668	0.097
)2HL005	MOIRA RIVER NEAR DELORO	0.007	0.020	0.101	0.009	0.036	0.118	0.307	0.073
)2HM004	WILTON CREEK NEAR NAPANEE	0.006	0.020	0.000	0.000	0.026	0.125	0.000	0.001
)2KC014	INDIAN RIVER NEAR PEMBROKE	0.280	0.017	0.197	0.007	0.481	0.010	0.496	0.000
)2KF010	CLYDE RIVER NEAR LANARK	0.059	0.008	0.231	0.030	0.277	0.010	0.560	0.080
)2LB007	SOUTH NATION RIVER AT SPENCERVILLE	0.000	0.022	0.000	0.000	0.016	0.132	0.000	0.000
)2LB013	SOUTH NATION RIVER AT CASSELMAN	0.097	0.003	0.904	0.651	0.529	0.022	1.607	1.161
	AVG	0.149	0.064	0.290	0.083	0.379	0.250	0.606	0.161
	STD	0.252	0.138	0.328	0.201	0.500	0.513	0.583	0.356
	SUM	1.340	0.573	2.612	0.748	3.412	2.247	5.453	1.448
	N.S.R^2			-0.305				0.356	

TABLE A.9

SUMMARY OF REGRESSION RESULTS, SOUTHEASTERN REGION
(WITH STATIONS 02LB013 AND 02KC004 REMOVED)

Station Number	River Name and Gauge Location	7Q20 Qo	(Qo-Qm)^2	R7Q20	(Qs-Qo)^2	7Q2 Qo	(Qo-Qm)^2	R7Q2	(Qs-Qo)^2
02HE001	BLOOMFIELD CREEK AT BLOOMFIELD	0.004	0.018	0.042	0.001	0.010	0.111	0.189	0.032
02HK003	CROWE RIVER AT MARMORA	0.823	0.470	0.849	0.001	1.680	1.787	1.627	0.003
02HL004	SKOOTAMATTA RIVER NEAR ACTINOLITE	0.064	0.005	0.287	0.050	0.357	0.000	0.668	0.097
02HL005	MOIRA RIVER NEAR DELORO	0.007	0.017	0.101	0.009	0.036	0.094	0.307	0.073
02HM004	WILTON CREEK NEAR NAPANEE	0.006	0.017	0.000	0.000	0.026	0.101	0.000	0.001
02KF010	CLYDE RIVER NEAR LANARK	0.059	0.006	0.231	0.030	0.277	0.004	0.560	0.080
02LB007	SOUTH NATION RIVER AT SPENCERVILLE	0.000	0.019	0.000	0.000	0.016	0.107	0.000	0.000
	AVG	0.138	0.079	0.216	0.013	0.343	0.315	0.479	0.041
	STD	0.281	0.160	0.279	0.018	0.561	0.603	0.525	0.039
	SUM	0.963	0.553	1.511	0.090	2.402	2.205	3.351	0.286
	N.S.R^2			0.84				0.87	

APPENDIX B
INDEX METHOD

The observed and estimated low flows by Index Method along with the calculation of Nash-Sutcliffe, R^2, for the Central, Southeastern and combined regions are presented in Tables B.1, B.2 and B.3, respectively.

The $7Q_2$ low flows for the Central, Southeastern and the combined regions are estimated from Figure 5.1 using the drainage area of the respective station. The $7Q_{20}$ low flows for all these regions are estimated by multiplying the $7Q_2$ values by the ratio of $7Q_{20}/7Q_2$ derived from the appropriate figures for the Central, Southeastern and combined regions. The observed and estimated low flows along with the calculation of N.S.R.^{2} for these regions is presented in Appendix B. The observed and simulated $7Q_2$ and $7Q_{20}$ for the Central, Southeastern and combined regions are presented in Figures 6.3, 6.4 and 6.5 respectively.

TABLE B.1

SIMULATION RESULTS BY INDEX METHOD

(CENTRAL REGION)

Test Station	Drainage Area of Test Station (km^2)	7q2 (m^3/s) Qo	r7q2 (m^3/s) Qs	(Qs-Qo)^2	(Qo-Qm)^2	7q20 (m^3/s) Qo	* r7q20 (m^3/s) Qs	(Qs-Qo)^2	(Qo-Qm)^2
02EB004	1390	4.508	3.100	1.982	14.406	1.459	1.473	0.000	1.262
02EC010	42.9	0.020	0.125	0.011	0.480	0.013	0.059	0.002	0.104
02EC103	332	0.865	0.750	0.013	0.023	0.718	0.356	0.131	0.146
02ED010	127	0.066	0.340	0.075	0.418	0.033	0.162	0.017	0.092
02ED102	211	0.465	0.500	0.001	0.061	0.388	0.238	0.023	0.003
02HB004	199	0.077	0.450	0.139	0.404	0.005	0.214	0.044	0.109
02HB012	82.6	0.066	0.200	0.018	0.418	0.041	0.095	0.003	0.087
02HC003	800	1.032	1.750	0.516	0.102	0.546	0.831	0.081	0.044
02HC009	197	0.157	0.450	0.086	0.309	0.080	0.214	0.018	0.065
02HD004	42.7	0.197	0.125	0.005	0.266	0.134	0.059	0.006	0.041
02HD008	95.8	0.432	0.250	0.033	0.079	0.288	0.119	0.029	0.002
02HH001	241	0.665	0.600	0.004	0.002	0.324	0.285	0.002	0.000
	Maximum	4.508	3.100	1.982	14.406	1.459	1.473	0.131	1.262
	Average	0.713	0.720	0.240	1.414	0.336	0.342	0.029	0.163
	Minimum	0.020	0.125	0.001	0.002	0.005	0.059	0.000	0.000
	Sum	8.550	8.640	2.884	16.967	4.029	4.104	0.354	1.955
	N.S. R^2		0.83				0.82		

* The $7Q_{20}/7Q_2$ ratio from Figure 5.1 (c) is 0.475

TABLE B.2

SIMULATION RESULTS BY INDEX METHOD

(SOUTHEASTERN REGION)

Test Station	Drainage Area (km^2)	7q2 (m^3/s) Qo	r7q2 (m^3/s) Qs	(Qs-Qo)^2	(Qo-Qm)^2	7q20 (m^3/s) Qo	* r7q20 (m^3/s) Qs	(Qs-Qo)^2	(Qo-Qm)^2
02HE001	13.9	0.010	0.000	0.000	0.136	0.004	0.000	0.000	0.021
02HK003	1990	1.680	3.077	1.952	1.692	0.823	0.702	0.015	0.454
02HL004	712	0.357	0.738	0.145	0.000	0.064	0.168	0.011	0.007
02HL005	308	0.036	0.230	0.038	0.118	0.007	0.052	0.002	0.020
02HM004	112	0.026	0.000	0.001	0.125	0.006	0.000	0.000	0.020
02KC014	443	0.481	0.460	0.000	0.010	0.280	0.105	0.031	0.017
02KF010	614	0.277	0.840	0.317	0.010	0.059	0.192	0.018	0.008
02LB007	246	0.016	0.154	0.019	0.132	0.000	0.035	0.001	0.022
02LB013	2410	0.529	4.000	12.048	0.022	0.097	0.912	0.664	0.003
	Maximum	1.680	4.000	12.048	1.692	0.823	0.912	0.664	0.454
	Average	0.379	1.055	1.613	0.250	0.149	0.241	0.082	0.064
	Minimum	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.003
	Sum	3.412	9.499	14.519	2.247	1.340	2.166	0.741	0.573
	N.S.R^2		-5.463				-0.293		

* The $7Q_{20}/7Q_2$ ratio from Figure 5.2 (c) is 0.228

TABLE B.3

SIMULATION RESULTS BY INDEX METHOD

(COMBINED CENTRAL AND SOUTHEASTERN REGION)

Test Station	Drainage Area of Test Station (km^2)	7q2 (m^3/s) Qo	r7q2 (m^3/s) Qs	(Qs-Qo)^2	(Qo-Qm)^2	7q20 (m^3/s) Qo	* r7q20 (m^3/s) Qs	(Qs-Qo)^2	(Qo-Qm)^2
02EB004	1390	4.508	2.639	3.493	15.511	1.459	1.056	0.163	1.448
02EC010	42.9	0.020	0.082	0.004	0.302	0.013	0.033	0.000	0.059
02EC103	332	0.865	0.631	0.055	0.087	0.718	0.252	0.217	0.214
02ED010	127	0.066	0.241	0.031	0.254	0.033	0.096	0.004	0.050
02ED102	211	0.465	0.401	0.004	0.011	0.388	0.160	0.052	0.018
02HB004	199	0.077	0.378	0.091	0.243	0.005	0.151	0.021	0.063
02HB012	82.6	0.066	0.157	0.008	0.254	0.041	0.063	0.000	0.046
02HC003	800	1.032	1.518	0.236	0.214	0.546	0.607	0.004	0.084
02HC009	197	0.157	0.374	0.047	0.170	0.080	0.150	0.005	0.031
02HD004	42.7	0.197	0.081	0.013	0.139	0.134	0.032	0.010	0.015
02HD008	95.8	0.432	0.182	0.063	0.019	0.288	0.073	0.046	0.001
02HH001	241	0.665	0.458	0.043	0.009	0.324	0.183	0.020	0.005
02HE001	13.9	0.010	0.026	0.000	0.313	0.004	0.010	0.000	0.063
02HK003	1990	1.680	3.780	4.410	1.233	0.823	1.512	0.475	0.322
02HL004	712	0.357	1.352	0.990	0.045	0.064	0.541	0.227	0.037
02HL005	308	0.036	0.585	0.301	0.285	0.007	0.234	0.052	0.062
02HM004	112	0.026	0.212	0.035	0.296	0.006	0.085	0.006	0.062
02KC014	443	0.481	0.842	0.130	0.008	0.280	0.337	0.003	0.001
02KF010	614	0.277	1.166	0.790	0.086	0.059	0.466	0.166	0.039
02LB007	246	0.016	0.468	0.204	0.306	0.000	0.187	0.035	0.065
02LB013	2410	0.529	4.580	16.411	0.002	0.097	1.832	3.010	0.025
	Maximum	4.508	4.580	16.411	15.511	1.459	1.832	3.010	1.448
	Average	0.570	0.960	1.303	0.942	0.256	0.384	0.215	0.129
	Minimum	0.010	0.026	0.000	0.002	0.000	0.010	0.000	0.001
	Sum	11.962	20.153	27.359	19.785	5.369	8.061	4.517	2.708
	N.S.R^2		-0.383				-0.668		

* The $7Q_{20}/7Q_2$ ratio from Figure 5.3 (c) is 0.4

APPENDIX C
ISOLINE METHOD

The data base for estimating low flows by isoline method is presented in Tables D.1(a) and D.2(a) and D.3(a) for the Central, Southeastern and combined regions, respectively. The summaries of the simulation results by this method along with the calculation of Nash-Sutcliffe, R^2, for the Central, Southeastern and the combined regions are presented in Tables C.1, C.2, and C.3 respectively.

The Isoline maps were developed for the observed unit area low flows of $7Q_2$ for the development stations of the Central, Southeastern and the combined region (see Figures 5.4, 5.5 and 5.6). The $7Q_2$ unit low flows were estimated for the test stations in the Central and Southeastern regions by interpolating the values between the contour lines. The $7Q_{20}$ low flows were then determined by multiplying the estimated $7Q_2$ and $7Q_{20}/7Q_2$ ratio determined from the appropriate figures for the Central, Southeastern and combined regions (i.e. ratios developed in Index Method). The data base for estimation of low flows and calculation of N.S.$R.^2$ is presented in Appendix D. The results of this analysis are presented in Figures 6.6, 6.7 and 6.8 for the Central, Southeastern and combined regions, respectively. The N.S.$R.^2$ for test stations by the Isoline method is presented in Table 6.2.

TABLE C.1

SIMULATION RESULTS BY ISOLINE METHOD

(CENTRAL REGION)

Test Station	Drainage Area of Test Station (km^2)	7q2 (m^3/s) Qo	r7q2 (m^3/s) Qs	(Qs-Qo)^2	(Qo-Qm)^2	7q20 (m^3/s) Qo	r7q20 (m^3/s) Qs	(Qs-Qo)^2	(Qo-Qm)^2
02EB004	1390	4.508	4.518	0.000	14.406	1.459	2.146	0.472	1.262
02EC010	42.9	0.020	0.034	0.000	0.480	0.013	0.016	0.000	0.104
02EC103	332	0.865	0.498	0.135	0.023	0.718	0.237	0.231	0.146
02ED010	127	0.066	0.127	0.004	0.418	0.033	0.060	0.001	0.092
02ED102	211	0.465	0.580	0.013	0.061	0.388	0.276	0.013	0.003
02HB004	199	0.077	0.398	0.103	0.404	0.005	0.189	0.034	0.109
02HB012	82.6	0.066	0.165	0.010	0.418	0.041	0.078	0.001	0.087
02HC003	800	1.032	0.400	0.399	0.102	0.546	0.190	0.127	0.044
02HC009	197	0.157	0.433	0.076	0.309	0.080	0.206	0.016	0.065
02HD004	42.7	0.197	0.278	0.007	0.266	0.134	0.132	0.000	0.041
02HD008	95.8	0.432	0.575	0.020	0.079	0.288	0.273	0.000	0.002
02HH001	241	0.665	0.410	0.065	0.002	0.324	0.195	0.017	0.000
	Maximum	4.508	4.518	0.399	14.406	1.459	2.146	0.472	1.262
	Average	0.713	0.701	0.069	1.414	0.336	0.333	0.076	0.163
	Minimum	0.020	0.034	0.000	0.002	0.005	0.016	0.000	0.000
	Sum	8.550	8.416	0.832	16.967	4.029	3.998	0.911	1.955
	N.S. R^2		0.95				0.53		

TABLE C.2
SIMULATION RESULTS BY ISOLINE METHOD
(SOUTHEASTERN REGION)

Test Station	Drainage Area (km^2)	7q2 (m^3/s) Qo	r7q2 (m^3/s) Qs	(Qs-Qo)^2	(Qo-Qm)^2	7q20 (m^3/s) Qo	r7q20 (m^3/s) Qs	(Qs-Qo)^2	(Qo-Qm)^2
02HE001	13.9	0.010	0.007	0.000	0.136	0.004	0.002	0.000	0.021
02HK003	1990	1.680	1.990	0.096	1.692	0.823	0.454	0.136	0.454
02HL004	712	0.357	0.712	0.126	0.000	0.064	0.162	0.010	0.007
02HL005	308	0.036	0.154	0.014	0.118	0.007	0.035	0.001	0.020
02HM004	112	0.026	0.112	0.007	0.125	0.006	0.026	0.000	0.020
02KC014	443	0.481	1.063	0.339	0.010	0.280	0.242	0.001	0.017
02KF010	614	0.277	0.246	0.001	0.010	0.059	0.056	0.000	0.008
02LB007	246	0.016	0.025	0.000	0.132	0.000	0.006	0.000	0.022
02LB013	2410	0.529	0.964	0.189	0.022	0.097	0.220	0.015	0.003
	Maximum	1.680	1.990	0.339	1.692	0.823	0.454	0.136	0.454
	Average	0.379	0.586	0.086	0.250	0.149	0.134	0.018	0.064
	Minimum	0.010	0.007	0.000	0.000	0.000	0.002	0.000	0.003
	Sum	3.412	5.273	0.772	2.247	1.340	1.203	0.164	0.573
	N.S.R^2		0.656				0.715		

TABLE C.3

SIMULATION RESULTS BY ISOLINE METHOD

(COMBINED CENTRAL AND SOUTHEASTERN REGION)

Test Station	Drainage Area of Test Station (km^2)	7q2 (m^3/s) Qo	r7q2 (m^3/s) Qs	(Qs-Qo)^2	(Qo-Qm)^2	7q20 (m^3/s) Qo	r7q20 (m^3/s) Qs	(Qs-Qo)^2	(Qo-Qm)^2
02EB004	1390	4.508	4.518	0.000	15.511	1.459	1.807	0.121	1.448
02EC010	42.9	0.020	0.034	0.000	0.302	0.013	0.014	0.000	0.059
02EC103	332	0.865	0.498	0.135	0.087	0.718	0.199	0.269	0.214
02ED010	127	0.066	0.127	0.004	0.254	0.033	0.051	0.000	0.050
02ED102	211	0.465	0.580	0.013	0.011	0.388	0.232	0.024	0.018
02HB004	199	0.077	0.398	0.103	0.243	0.005	0.159	0.024	0.063
02HB012	82.6	0.066	0.165	0.010	0.254	0.041	0.066	0.001	0.046
02HC003	800	1.032	0.400	0.399	0.214	0.546	0.160	0.149	0.084
02HC009	197	0.157	0.433	0.076	0.170	0.080	0.173	0.009	0.031
02HD004	42.7	0.197	0.278	0.007	0.139	0.134	0.111	0.001	0.015
02HD008	95.8	0.432	0.575	0.020	0.019	0.288	0.230	0.003	0.001
02HH001	241	0.665	0.410	0.065	0.009	0.324	0.164	0.026	0.005
02HE001	13.9	0.010	0.007	0.000	0.313	0.004	0.003	0.000	0.063
02HK003	1990	1.680	1.990	0.096	1.233	0.823	0.796	0.001	0.322
02HL004	712	0.357	0.712	0.126	0.045	0.064	0.285	0.049	0.037
02HL005	308	0.036	0.154	0.014	0.285	0.007	0.062	0.003	0.062
02HM004	112	0.026	0.112	0.007	0.296	0.006	0.045	0.002	0.062
02KC014	443	0.481	1.063	0.339	0.008	0.280	0.425	0.021	0.001
02KF010	614	0.277	0.246	0.001	0.086	0.059	0.098	0.002	0.039
02LB007	246	0.016	0.025	0.000	0.306	0.000	0.010	0.000	0.065
02LB013	2410	0.529	0.964	0.189	0.002	0.097	0.386	0.084	0.025
	Maximum	4.508	4.518	0.399	15.511	1.459	1.807	0.269	1.448
	Average	0.570	0.652	0.076	0.942	0.256	0.261	0.037	0.129
	Minimum	0.010	0.007	0.000	0.002	0.000	0.003	0.000	0.001
	Sum	11.962	13.689	1.605	19.785	5.369	5.476	0.787	2.708
	N.S.R^2		0.919				0.709		

APPENDIX D
STATION PRORATION METHOD

The data base for estimating low flows by the station proration method is presented in Tables D.1 and D.2 for the Central and Southeastern regions, respectively. The summaries of the simulation results by this method along with the calculation of Nash-Sutcliffe, R^2, for the Central, Southeastern and the combined regions are presented in Tables D.3, D.4 and D.5 respectively.

The method of reciprocal distance was used in the proration estimation, i.e. the distances from the test stations to nearby gauges were measured and the weighted average of the unit low flows was estimated for the test stations by using the reciprocal of distances to nearby stations and their observed unit area low flows. The figures from which these distances were measured and the tables presenting the data base for estimation of low flows and calculation of Nash-Sutcliffe R^2 are presented in Appendix C. The N.S.R.^{2} for estimation of $7Q_2$ and $7Q_{20}$ for the Central, Southeastern and combined regions are presented in Table 6.3. The results of this analysis for these regions are presented in Figures 6.9, 6.10 and 6.11.

DATA BASE FOR ESTIMATING LOW FLOWS

BY MAPPING PRORATION

(CENTRAL REGION)

Test Station	Nearby Station	Distance from Test Station (Units)	Reciprocal of Distance from Test Station (Units)	Drainage Area of Test Station (km^2)	7q2 (m^3/s)	Unit 7q2 (L/s/km^2)	Unit r7q2 (L/s/km^2)	r7q2	7q20	Unit 7q20 (L/s/km^2)	Unit r7q20 (L/s/km^2)	r7q20
02EB004				1390	4.508	3.243	3.559	4.947	1.459	1.050	1.943	2.701
	02EB013	2.2	0.45	593	2.143	3.614			1.362	2.297		
	02EB008	6	0.17	1390	4.738	3.409			1.360	0.978		
02EC010				42.9	0.020	0.466	1.981	0.085	0.013	0.303	1.193	0.051
	02ED100	3.5	0.29	86	0.146	1.698			0.055	0.640		
	02HC032	3.9	0.26	94.8	0.071	0.749			0.052	0.549		
	02HC012	4.1	0.24	169	0.482	2.852			0.308	1.822		
	02HC023	3.6	0.28	69.2	0.183	2.645			0.125	1.806		
02EC103				332	0.865	2.605	1.033	0.343	0.718	2.163	0.578	0.192
	02EC012	4.2	0.24	324	0.357	1.102			0.279	0.861		
	02EC008	3.6	0.28	274	0.267	0.974			0.092	0.336		
02ED010				127	0.066	0.520	0.784	0.100	0.033	0.260	0.485	0.062
	02ED009	2.6	0.38	94.8	0.026	0.274			0.010	0.105		
	02EC012	9.8	0.10	324	0.357	1.102			0.279	0.861		
	02ED003	6.9	0.14	1180	2.258	1.914			1.449	1.228		
02ED102				211	0.465	2.204	3.476	0.733	0.388	1.839	2.528	0.533
	02ED003	3.7	0.27	1180	2.258	1.914			1.449	1.228		
	02ED103	2.3	0.43	195	0.882	4.523			0.695	3.564		
	02ED005	6	0.17	295	0.967	3.278			0.570	1.932		
02HB004				199	0.077	0.387	2.282	0.454	0.005	0.025	1.071	0.213
	02HB002	3.7	0.27	795	2.087	2.625			0.941	1.184		
	02HB005	2.5	0.40	95.6	0.229	2.395			0.064	0.669		
	02HB011	2.5	0.40	235	0.455	1.936			0.328	1.396		
02HB012				82.6	0.066	0.799	1.608	0.133	0.041	0.496	0.799	0.066
	02HB011	4.2	0.24	235	0.455	1.936			0.328	1.396		
	02HB005	6.8	0.15	95.6	0.229	2.395			0.064	0.669		
	02HB004	6.3	0.16	199	0.077	0.387			0.005	0.025		
02HC003				800	1.032	1.290	1.428	1.143	0.546	0.683	0.658	0.526
	02HC030	3.4	0.29	204	0.228	1.118			0.142	0.696		
	02HC033	1.8	0.56	70.6	0.096	1.360			0.045	0.637		
	02HC005	3	0.33	88.1	0.160	1.816			0.058	0.658		
02HC009				197	0.157	0.797	1.467	0.289	0.080	0.406	1.042	0.205
	02HC025	1.1	0.91	303	0.820	2.706			0.591	1.950		
	02HC031	2.8	0.36	148	0.009	0.061			0.000	0.000		
	02HC034	2.3	0.43	194	0.006	0.031			0.000	0.000		
02HD004				42.7	0.197	4.614	6.923	0.296	0.134	3.138	4.342	0.185
	02HD003	0.3	3.33	67.3	0.484	7.192			0.299	4.443		
	02HD009	4.3	0.23	82.6	0.341	4.128			0.228	2.760		
	02HD012	3.8	0.26	232	1.388	5.983			1.036	4.466		
02HD008				95.8	0.432	4.509	3.498	0.335	0.288	3.006	2.323	0.223
	02HC018	2.6	0.38	106	0.104	0.981			0.042	0.396		
	02HD006	4.3	0.23	82.9	0.503	6.068			0.353	4.258		
	02HD009	6.3	0.16	82.6	0.341	4.128			0.228	2.760		
	02HC019	5.3	0.19	93.5	0.461	4.930			0.327	3.497		
02HH001				241	0.665	2.759	2.134	0.514	0.324	1.344	0.870	0.210
	02HH002	5.4	0.19	326	0.702	2.153			0.177	0.543		
	02HJ002	9.2	0.11	7360	18.690	2.539			13.740	1.867		
	02HK005	7.8	0.13	456	0.803	1.761			0.226	0.496		

TABLE D.2

DATA BASE FOR ESTIMATING LOW FLOWS

BY MAPPING PRORATION

(SOUTHEASTERN REGION)

Test Station	Nearby Station	Distance from Test Station (Units)	Reciprocal of Distance from Test Station (Units)	Drainage Area (km^2)	7q2 (m^3/s)	Unit 7q2 (L/s/ km^2)	Unit r7q2 (L/s/ km^2)	r7q2 (m^3/s)	7q20 (m^3/s)	Unit 7q20 (L/s/ km^2)	Unit r7q20 (L/s/ km^2)	r7q20 (m^3/s)
02HE001				13.9	0.010	0.719	0.173	0.002	0.004	0.288	0.058	0.001
	02HE002	2.8	0.36	114	0.002	0.018			0.000	0.000		
	02HM003	5.7	0.18	891	0.145	0.163			0.034	0.038		
	02HL001	6.8	0.15	2620	1.477	0.564			0.582	0.222		
02HK003				1990	1.680	0.844	0.213	0.424	0.823	0.414	0.032	0.063
	02HK006	1.2	0.83	541	0.157	0.290			0.021	0.039		
	02HL005	1.5	0.67	308	0.036	0.117			0.007	0.023		
02HL004				712	0.357	0.501	0.967	0.689	0.064	0.090	0.132	0.094
	02HL003	0.6	1.67	401	0.450	1.122			0.061	0.152		
	02HL005	5.4	0.19	308	0.036	0.117			0.007	0.023		
	02HK006	6.7	0.15	541	0.157	0.290			0.021	0.039		
02HL005				308	0.036	0.117	0.567	0.175	0.007	0.023	0.226	0.070
	02HK003	1.5	0.67	1990	1.680	0.844			0.823	0.414		
	02HK006	1.5	0.67	541	0.157	0.290			0.021	0.039		
02HM004				112	0.026	0.232	1.258	0.141	0.006	0.054	0.363	0.041
	02HM007	2	0.50	694	1.159	1.670			0.355	0.512		
	02HM006	2.2	0.45	150	0.095	0.633			0.039	0.260		
	02HM002	5.7	0.18	189	0.322	1.704			0.039	0.206		
02KC014				443	0.481	1.086	2.740	1.214	0.280	0.632	1.592	0.705
	02KB001	4.3	0.23	4120	11.290	2.740			6.560	1.592		
02KF010				614	0.277	0.451	1.201	0.737	0.059	0.096	0.526	0.323
	02KF014	1.4	0.71	277	0.109	0.394			0.000	0.000		
	02KF001	1.5	0.67	2620	5.412	2.066			2.855	1.090		
02LB007				246	0.016	0.065	0.145	0.036	0.000	0.000	0.008	0.002
	02LA006	4.5	0.22	409	0.076	0.186			0.008	0.020		
	02LB017	3.3	0.30	69.2	0.008	0.116			0.000	0.000		
02LB013				2410	0.529	0.220	0.341	0.823	0.097	0.040	0.172	0.416
	02LB005	4.7	0.21	3810	1.100	0.289			0.118	0.031		
	02LB008	2.2	0.45	440	0.161	0.366			0.105	0.239		

TABLE D.3

SIMULATION RESULTS BY MAPPING PRORATION METHOD

(CENTRAL REGION)

Test Station	Drainage Area of Test Station (km^2)	7q2 (m^3/s) Qo	r7q2 (m^3/s) Qs	(Qs-Qo)^2	(Qo-Qm)^2	7q20 (m^3/s) Qo	r7q20 (m^3/s) Qs	(Qs-Qo)^2	(Qo-Qm)^2
02EB004	1390	4.508	4.947	0.192	14.406	1.459	2.701	1.542	1.262
02EC010	42.9	0.020	0.085	0.004	0.480	0.013	0.051	0.001	0.104
02EC103	332	0.865	0.343	0.272	0.023	0.718	0.192	0.277	0.146
02ED010	127	0.066	0.100	0.001	0.418	0.033	0.062	0.001	0.092
02ED102	211	0.465	0.733	0.072	0.061	0.388	0.533	0.021	0.003
02HB004	199	0.077	0.454	0.142	0.404	0.005	0.213	0.043	0.109
02HB012	82.6	0.066	0.133	0.004	0.418	0.041	0.066	0.001	0.087
02HC003	800	1.032	1.143	0.012	0.102	0.546	0.526	0.000	0.044
02HC009	197	0.157	0.289	0.017	0.309	0.080	0.205	0.016	0.065
02HD004	42.7	0.197	0.296	0.010	0.266	0.134	0.185	0.003	0.041
02HD008	95.8	0.432	0.335	0.009	0.079	0.288	0.223	0.004	0.002
02HH001	241	0.665	0.514	0.023	0.002	0.324	0.210	0.013	0.000
	Maximum	4.508	4.947	0.272	14.406	1.459	2.701	1.542	1.262
	Average	0.713	0.781	0.063	1.414	0.336	0.431	0.160	0.163
	Minimum	0.020	0.085	0.001	0.002	0.005	0.051	0.000	0.000
	Sum	8.550	9.371	0.760	16.967	4.029	5.167	1.922	1.955
	N.S. R^2		0.96				0.02		

TABLE D.4

SIMULATION RESULTS BY MAPPING PRORATION METHOD

(SOUTHEASTERN REGION)

Test Station	Drainage Area (km^2)	7q2 (m^3/s) Qo	r7q2 (m^3/s) Qs	(Qs-Qo)^2	(Qo-Qm)^2	7q20 (m^3/s) Qo	r7q20 (m^3/s) Qs	(Qs-Qo)^2	(Qo-Qm)^2
02HE001	13.9	0.010	0.002	0.000	0.136	0.004	0.001	0.000	0.021
02HK003	1990	1.680	0.424	1.577	1.692	0.823	0.063	0.578	0.454
02HL004	712	0.357	0.689	0.110	0.000	0.064	0.094	0.001	0.007
02HL005	308	0.036	0.175	0.019	0.118	0.007	0.070	0.004	0.020
02HM004	112	0.026	0.141	0.013	0.125	0.006	0.041	0.001	0.020
02KC014	443	0.481	1.214	0.537	0.010	0.280	0.705	0.181	0.017
02KF010	614	0.277	0.737	0.212	0.010	0.059	0.323	0.070	0.008
02LB007	246	0.016	0.036	0.000	0.132	0.000	0.002	0.000	0.022
02LB013	2410	0.529	0.823	0.086	0.022	0.097	0.416	0.101	0.003
	Maximum	1.680	1.214	1.577	1.692	0.823	0.705	0.578	0.454
	Average	0.379	0.471	0.284	0.250	0.149	0.190	0.104	0.064
	Minimum	0.010	0.002	0.000	0.000	0.000	0.001	0.000	0.003
	Sum	3.412	4.240	2.555	2.247	1.340	1.714	0.936	0.573
	N.S.R^2		-0.137				-0.632		

TABLE D.5

SIMULATION RESULTS BY MAPPING PRORATION METHOD

(COMBINED CENTRAL AND SOUTHEASTERN REGION)

Test Station	Drainage Area of Test Station (km^2)	7q2 (m^3/s) Qo	r7q2 (m^3/s) Qs	(Qs-Qo)^2	(Qo-Qm)^2	7q20 (m^3/s) Qo	r7q20 (m^3/s) Qs	(Qs-Qo)^2	(Qo-Qm)^2
02EB004	1390	4.508	4.947	0.192	15.511	1.459	2.701	1.542	1.448
02EC010	42.9	0.020	0.085	0.004	0.302	0.013	0.051	0.001	0.059
02EC103	332	0.865	0.343	0.272	0.087	0.718	0.192	0.277	0.214
02ED010	127	0.066	0.100	0.001	0.254	0.033	0.062	0.001	0.050
02ED102	211	0.465	0.733	0.072	0.011	0.388	0.533	0.021	0.018
02HB004	199	0.077	0.454	0.142	0.243	0.005	0.213	0.043	0.063
02HB012	82.6	0.066	0.133	0.004	0.254	0.041	0.066	0.001	0.046
02HC003	800	1.032	1.143	0.012	0.214	0.546	0.526	0.000	0.084
02HC009	197	0.157	0.289	0.017	0.170	0.080	0.205	0.016	0.031
02HD004	42.7	0.197	0.296	0.010	0.139	0.134	0.185	0.003	0.015
02HD008	95.8	0.432	0.335	0.009	0.019	0.288	0.223	0.004	0.001
02HH001	241	0.665	0.514	0.023	0.009	0.324	0.210	0.013	0.005
02HE001	13.9	0.010	0.002	0.000	0.313	0.004	0.001	0.000	0.063
02HK003	1990	1.680	0.424	1.577	1.233	0.823	0.063	0.578	0.322
02HL004	712	0.357	0.689	0.110	0.045	0.064	0.094	0.001	0.037
02HL005	308	0.036	0.175	0.019	0.285	0.007	0.070	0.004	0.062
02HM004	112	0.026	0.141	0.013	0.296	0.006	0.041	0.001	0.062
02KC014	443	0.481	1.214	0.537	0.008	0.280	0.705	0.181	0.001
02KF010	614	0.277	0.737	0.212	0.086	0.059	0.323	0.070	0.039
02LB007	246	0.016	0.036	0.000	0.306	0.000	0.002	0.000	0.065
02LB013	2410	0.529	0.823	0.086	0.002	0.097	0.416	0.101	0.025
	Maximum	4.508	4.947	1.577	15.511	1.459	2.701	1.542	1.448
	Average	0.570	0.648	0.158	0.942	0.256	0.328	0.136	0.129
	Minimum	0.010	0.002	0.000	0.002	0.000	0.001	0.000	0.001
	Sum	11.962	13.611	3.315	19.785	5.369	6.881	2.858	2.708
	N.S.R^2		0.832				-0.055		

APPENDIX E
ANALYSES OF EXISTING TECHNIQUES

To assess the applicability of the previous results extrapolated to the present study area, the previously developed techniques with the previously determined coefficients and constants were utilized to predict low flow characteristics for stations located in the Central, Southeastern Regions and the combined regions. The analysis is summarized in Tables E.1, E.2 and E.3 for the above regions respectively.

TABLE E.1

TESTING PREVIOUS REGIONAL ANALYSIS OF LOW FLOW CHARACTERISTICS IN THE CENTRAL REGION

Station Number	Record Length (years)	Drainage Area (km^2)	B.F.I. (%)	Length (km)	7Q2 Qo	(m^3/s) (Qo-Qm)^	7Q20 Qo	(m^3/s) (Qo-Qm)^	R7Q2 Qs	(m^3/s) (Qs-Qo)^2	R7Q20 Qs	(m^3/s) (Qs-Qo)^2	I7Q2 Qs	(m^3/s) (Qs-Qo)^2	I7Q20 Qs	(m^3/s) (Qs-Qo)^2	B7Q20 Qs	(m^3/s) (Qs-Qo)^2	U7Q20 Qs	(m^3/s) (Qs-Qo)^2
02EB008	41	1390.0	0.79	48.75	4.51	15.169	1.46	1.310	1.384	9.761	0.874	0.342	1.440	9.413	0.576	0.780	3.435	3.903	2.21	3.192
02EB013	46	593.0	0.68	38.00	4.74	17.013	1.36	1.094	0.729	16.075	0.429	0.867	0.643	16.769	0.257	1.216	1.152	0.043	0.61	0.038
02EC008	10	274.0	0.59	30.00	0.27	0.120	0.09	0.049	0.469	0.041	0.261	0.028	0.324	0.003	0.130	0.001	0.414	0.103	0.34	0.006
02EC009	22	181.0	0.45	29.00	0.29	0.103	0.15	0.027	0.219	0.005	0.097	0.003	0.231	0.004	0.092	0.003	0.151	0.000	0.06	0.131
02EC011	16	282.0	0.46	55.25	0.25	0.132	0.12	0.038	0.421	0.029	0.211	0.008	0.332	0.007	0.133	0.000	0.249	0.017	0.46	0.001
02EC012	13	324.0	0.50	32.50	0.36	0.064	0.28	0.001	0.320	0.002	0.161	0.014	0.374	0.000	0.150	0.017	0.349	0.005	0.27	0.023
02EC101	12	24.3	0.82	32.00	0.25	0.132	0.18	0.018	1.018	0.590	0.621	0.195	0.074	0.031	0.030	0.023	0.064	0.014	0.03	0.149
02ED003	34	1180.0	0.55	61.75	2.26	2.712	1.45	1.290	0.837	2.024	0.493	0.915	1.230	1.061	0.492	0.918	1.554	0.011	3.10	7.190
02ED005	19	295.0	0.61	50.50	0.97	0.127	0.57	0.065	0.648	0.104	0.365	0.042	0.345	0.391	0.138	0.187	0.474	0.009	0.75	0.107
02ED007	17	177.0	0.63	28.00	0.96	0.120	0.78	0.217	0.539	0.177	0.308	0.223	0.227	0.537	0.091	0.475	0.301	0.229	0.26	0.024
02ED009	11	94.8	0.33	15.50	0.03	0.340	0.01	0.093	0.012	0.000	-0.035	0.002	0.145	0.013	0.058	0.002	0.025	0.000	0.11	0.095
02ED011	14	168.0	0.65	14.00	0.46	0.023	0.22	0.009	0.533	0.005	0.308	0.008	0.218	0.060	0.087	0.017	0.302	0.007	0.57	0.024
02ED100	14	86.0	0.57	17.75	0.15	0.215	0.06	0.065	0.379	0.052	0.206	0.021	0.136	0.000	0.054	0.000	0.122	0.004	0.09	0.111
02ED103	14	195.0	0.71	37.50	0.88	0.071	0.70	0.149	0.770	0.012	0.455	0.060	0.245	0.403	0.098	0.362	0.407	0.086	0.31	0.011
02HB001	58	205.0	0.45	15.00	0.60	0.000	0.32	0.000	0.168	0.189	0.068	0.062	0.255	0.121	0.102	0.046	0.171	0.021	0.45	0.001
02HB005	24	95.6	0.53	16.50	0.23	0.147	0.06	0.065	0.302	0.005	0.156	0.009	0.146	0.007	0.058	0.000	0.117	0.003	0.06	0.126
02HB008	20	127.0	0.57	21.00	0.36	0.064	0.23	0.007	0.390	0.001	0.212	0.000	0.177	0.033	0.071	0.025	0.179	0.003	0.04	0.144
02HB011	19	235.0	0.64	30.00	0.45	0.027	0.33	0.000	0.571	0.015	0.328	0.000	0.285	0.027	0.114	0.047	0.411	0.007	0.08	0.117
02HB013	20	62.2	0.65	9.00	0.21	0.162	0.14	0.029	0.522	0.097	0.303	0.025	0.112	0.010	0.045	0.010	0.112	0.001	0.10	0.101
02HC005	35	88.1	0.40	18.00	0.16	0.205	0.06	0.066	0.104	0.003	0.025	0.001	0.138	0.000	0.055	0.000	0.053	0.000	0.24	0.033
02HC006	29	249.0	0.54	29.48	0.74	0.016	0.37	0.003	0.371	0.136	0.197	0.030	0.299	0.194	0.120	0.063	0.316	0.003	0.67	0.062
02HC012	25	169.0	0.60	24.57	0.48	0.018	0.31	0.000	0.462	0.000	0.259	0.003	0.219	0.068	0.088	0.049	0.263	0.002	0.26	0.025
02HC013	17	88.1	0.43	15.20	0.23	0.147	0.08	0.055	0.138	0.008	0.048	0.001	0.138	0.008	0.055	0.001	0.065	0.000	0.08	0.115
02HC017	19	63.2	0.26	20.30	0.05	0.322	0.00	0.097	-0.043	0.008	-0.072	0.006	0.113	0.005	0.045	0.002	-0.005	0.000	0.09	0.109
02HC018	24	106.0	0.46	21.50	0.10	0.259	0.04	0.074	0.202	0.010	0.088	0.002	0.156	0.003	0.062	0.000	0.094	0.003	0.24	0.034
02HC019	24	93.5	0.58	17.48	0.46	0.023	0.33	0.000	0.397	0.004	0.218	0.012	0.144	0.101	0.057	0.073	0.137	0.036	0.10	0.099
02HC022	26	186.0	0.37	28.05	0.14	0.226	0.07	0.060	0.105	0.001	0.022	0.002	0.236	0.010	0.094	0.001	0.084	0.000	0.13	0.085
02HC023	25	62.2	0.57	11.75	0.18	0.185	0.13	0.036	0.364	0.033	0.198	0.005	0.112	0.005	0.045	0.006	0.088	0.001	0.08	0.117
02HC024	25	316.0	0.49	37.50	1.39	0.599	1.16	0.719	0.332	1.112	0.167	0.991	0.366	1.042	0.146	1.031	0.325	0.700	0.39	0.001
02HC025	25	303.0	0.59	45.00	0.82	0.043	0.59	0.077	0.564	0.066	0.314	0.077	0.353	0.218	0.141	0.202	0.457	0.018	0.08	0.112
02HC028	23	77.7	0.34	17.50	0.09	0.275	0.05	0.072	0.029	0.004	-0.024	0.005	0.128	0.001	0.051	0.000	0.024	0.000	0.11	0.096
02HC029	23	130.0	0.43	20.00	0.42	0.038	0.26	0.003	0.152	0.071	0.056	0.040	0.180	0.057	0.072	0.034	0.096	0.026	0.23	0.037
02HC030	21	204.0	0.24	38.00	0.23	0.148	0.14	0.030	0.028	0.040	-0.034	0.031	0.254	0.001	0.102	0.002	-0.035	0.031	0.17	0.062
02HC031	18	148.0	0.23	24.00	0.01	0.365	0.00	0.099	-0.053	0.004	-0.081	0.006	0.198	0.036	0.079	0.006	-0.033	0.001	0.12	0.091
02HC032	21	94.8	0.44	21.00	0.07	0.294	0.05	0.069	0.170	0.010	0.068	0.000	0.145	0.005	0.058	0.000	0.075	0.001	0.18	0.055
02HC033	21	70.6	0.25	29.50	0.10	0.268	0.05	0.072	-0.013	0.012	-0.057	0.010	0.121	0.001	0.048	0.000	-0.009	0.003	0.05	0.137
02HC034	18	194.0	0.17	22.00	0.01	0.369	0.00	0.099	-0.100	0.011	-0.111	0.012	0.244	0.057	0.098	0.010	-0.099	0.010	0.03	0.152
02HD003	28	67.3	0.70	15.50	0.48	0.017	0.30	0.000	0.648	0.027	0.384	0.007	0.117	0.134	0.047	0.064	0.137	0.026	0.21	0.042
02HD006	28	82.9	0.59	22.00	0.50	0.012	0.35	0.002	0.432	0.005	0.240	0.013	0.133	0.137	0.053	0.090	0.125	0.052	0.24	0.034
02HD009	22	82.6	0.62	15.00	0.34	0.074	0.23	0.007	0.471	0.017	0.267	0.002	0.133	0.043	0.053	0.031	0.137	0.008	0.35	0.004
02HD010	22	64.8	0.62	17.50	0.32	0.088	0.20	0.014	0.478	0.026	0.271	0.006	0.115	0.040	0.046	0.022	0.107	0.008	0.29	0.017
02HD012	11	232.0	0.66	21.00	1.39	0.600	1.04	0.521	0.576	0.660	0.335	0.492	0.282	1.223	0.113	0.852	0.428	0.369	0.92	0.249
02HH002	15	326.0	0.65	30.00	0.70	0.008	0.18	0.019	0.595	0.011	0.344	0.028	0.376	0.106	0.150	0.001	0.586	0.167	0.54	0.014
02HJ001	25	110.0	0.40	18.50	0.08	0.289	0.03	0.084	0.106	0.001	0.026	0.000	0.160	0.007	0.064	0.002	0.066	0.002	0.14	0.080
02HJ003	20	282.0	0.62	28.50	0.16	0.209	0.02	0.085	0.523	0.134	0.297	0.075	0.332	0.031	0.133	0.012	0.466	0.197	0.18	0.058
02HK005	19	456.0	0.76	35.50	0.80	0.036	0.23	0.008	0.892	0.008	0.537	0.097	0.506	0.088	0.202	0.001	1.061	0.697	0.47	0.002
02HK006	14	541.0	0.62	60.00	0.16	0.208	0.02	0.086	0.772	0.378	0.439	0.175	0.391	0.188	0.236	0.046	0.895	0.763	0.26	0.027
				AVG	0.613	0.895	0.314	0.149	0.403	0.681	0.218	0.105	0.281	0.696	0.113	0.143	0.338	0.162	0.356	0.288
				STD	0.946	3.233	0.385	0.310	0.304	2.683	0.199	0.234	0.255	2.735	0.102	0.300	0.559	0.581	0.533	1.114
				SUM	28.825	42.082	14.769	6.982	18.933	31.985	10.241	4.955	13.227	32.702	5.291	6.729	15.892	7.592	16.716	13.543
				N.S.R^2					0.24		0.29		0.22		0.04		-0.09		-0.94	

nQy is the n day low flows with y years of recurrence interval.

R-Estimated by Regression Method, I-Index, B-Baseflow isolines and U-Mapping Prorotion.

TABLE E.2

TESTING PREVIOUS REGIONAL ANALYSIS

OF LOW FLOW CHARACTERISTICS

IN THE SOUTHEASTERN REGION

ion nber	Record Length (years)	Drainage Area (km^2)	B.F.I. (%)	Length (km)	7Q2 Qo	(m^3/s) (Qo-Qm)^	7Q20 Qo	(m^3/s) (Qo-Qm)^	R7Q2 Qs	(m^3/s) (Qs-Qo)^2	R7Q20 Qs	(m^3/s) (Qs-Qo)^2	I7Q2 Qs	(m^3/s) (Qs-Qo)^2	I7Q20 Qs	(m^3/s) (Qs-Qo)^2	B7Q20 Qs	(m^3/s) (Qs-Qo)^2	U7Q20 Qs	(m^3/s) (Qs-Qo)^2
001	67	2620.0	0.71	87.00	1.477	0.059	0.582	0.004	3.514	4.149	2.366	3.183	2.670	1.423	1.068	0.236	5.466	23.856	1.15	0.541
003	18	401.0	0.60	66.50	0.450	0.615	0.061	0.339	0.788	0.115	0.442	0.145	0.451	0.000	0.180	0.014	0.625	0.318	0.03	0.149
4002	30	189.0	0.66	20.00	0.322	0.832	0.039	0.365	0.550	0.052	0.318	0.078	0.239	0.007	0.096	0.003	0.340	0.090	0.06	0.129
4003	24	891.0	0.77	112.40	0.145	1.186	0.034	0.371	1.943	3.232	1.140	1.223	0.941	0.634	0.376	0.117	2.116	4.335	0.12	0.087
4005	10	155.0	0.49	27.00	0.025	1.462	0.000	0.413	0.272	0.061	0.132	0.018	0.205	0.032	0.082	0.007	0.159	0.025	0.03	0.153
4006	13	150.0	0.63	40.00	0.095	1.297	0.039	0.365	0.607	0.262	0.346	0.094	0.200	0.011	0.080	0.002	0.255	0.047	0.00	0.172
4007	10	694.0	0.78	50.50	1.159	0.006	0.355	0.083	1.080	0.006	0.653	0.089	0.744	0.172	0.298	0.003	1.682	1.760	0.09	0.111
003	20	7.0	0.50	5.00	0.001	1.520	0.000	0.413	0.230	0.052	0.110	0.012	0.057	0.003	0.023	0.001	0.008	0.000	0.00	0.176
001	67	4120.0	0.88	107.60	11.292	101.164	6.560	35.011	10.742	0.303	7.542	0.964	4.170	50.723	1.668	23.932	11.963	29.194	1.00	0.332
009	61	2380.0	0.68	90.00	4.762	12.447	2.830	4.783	2.930	3.355	1.938	0.795	2.430	5.438	0.972	3.452	4.622	3.212	4.02	12.994
011	12	269.0	0.33	35.00	0.059	1.381	0.010	0.401	0.097	0.001	0.013	0.000	0.319	0.068	0.128	0.014	0.070	0.004	0.88	0.208
012	11	203.0	0.61	37.50	0.278	0.914	0.181	0.213	0.550	0.074	0.310	0.017	0.253	0.001	0.101	0.006	0.326	0.021	0.26	0.027
013	11	280.0	0.67	32.50	0.150	1.175	0.021	0.387	0.651	0.251	0.379	0.128	0.330	0.032	0.132	0.012	0.530	0.259	0.01	0.164
014	12	277.0	0.59	53.00	0.109	1.266	0.000	0.413	0.629	0.270	0.350	0.123	0.327	0.048	0.131	0.017	0.418	0.175	0.11	0.094
004	34	3830.0	0.52	92.50	5.705	19.990	3.118	6.126	7.943	5.007	5.604	6.181	3.880	3.331	1.552	2.452	4.492	1.888	10.82	108.130
006	13	409.0	0.41	63.00	0.076	1.341	0.008	0.403	0.431	0.126	0.210	0.041	0.459	0.147	0.184	0.031	0.263	0.065	0.00	0.176
007	14	559.0	0.38	60.50	0.086	1.318	0.012	0.398	0.378	0.086	0.180	0.028	0.609	0.274	0.244	0.054	0.279	0.072	1.51	1.199
006	35	433.0	0.30	36.30	0.195	1.079	0.089	0.307	0.080	0.013	0.002	0.008	0.483	0.083	0.193	0.011	0.050	0.002	0.01	0.167
008	25	440.0	0.30	46.20	0.161	1.151	0.105	0.289	0.149	0.000	0.040	0.004	0.490	0.108	0.196	0.008	0.051	0.003	0.02	0.162
017	9	69.0	0.30	15.00	0.008	0.497	0.060	0.298	-0.021	0.302	-0.056	0.024	0.119	0.168	0.048	0.002	0.008	0.008	0.00	0.175
022	9	152.0	0.30	34.00	0.027	1.457	0.001	0.412	0.057	0.001	-0.013	0.000	0.202	0.031	0.081	0.006	0.018	0.000	0.02	0.161
001	26	404.0	0.37	26.00	0.044	1.416	0.004	0.408	0.103	0.004	0.022	0.000	0.454	0.168	0.182	0.032	0.183	0.032	0.01	0.168
				AVG	1.234	6.981	0.643	2.373	1.532	0.806	1.001	0.598	0.911	2.859	0.364	1.382	1.542	2.971	0.916	5.713
				STD	2.642	21.043	1.540	7.276	2.660	1.510	1.885	1.408	1.182	10.523	0.473	4.994	2.787	7.578	2.338	22.508
				SUM	27.147	153.571	14.146	52.203	33.703	17.721	22.028	13.154	20.032	62.901	8.013	30.413	33.924	65.366	20.151	125.676
				N.S.R^2					0.88		0.75		0.59		0.42		-0.25		-1.41	

s the n day low flows with y years of recurrence interval.

mated by Regression Method, I-Index, B-Baseflow isolines and U-Mapping Proration.

TABLE E.3

TESTING PREVIOUS REGIONAL ANALYSIS OF LOW FLOW CHARACTERISTICS IN THE COMBINED REGION

Station Number	Record Length (years)	Drainage Area (km^2)	B.F.I. (%)	Length (km)	7Q2 Qo	(m^3/s) (Qo-Qm)^	7Q20 Qo	(m^3/s) (Qo-Qm)^	R7Q2 Qs	(m^3/s) (Qs-Qo)^2	R7Q20 Qs	(m^3/s) (Qs-Qo)^2	I7Q2 Qs	(m^3/s) (Qs-Qo)^2	I7Q20 Qs	(m^3/s) (Qs-Qo)^2	B7Q20 Qs	(m^3/s) (Qs-Qo)^2	U7Q20 Qs	(m^3/s) (Qs-Qo)^2
2EB008	41	1390.0	0.79	48.75	4.51	13.666	1.46	1.081	1.384	9.761	0.874	0.342	1.440	9.413	0.576	0.780	3.435	3.903	2.21	3.192
2EB013	46	593.0	0.68	38.00	4.74	15.420	1.36	0.885	0.729	16.075	0.429	0.867	0.643	16.769	0.257	1.216	1.152	0.043	0.61	0.038
2EC008	10	274.0	0.59	30.00	0.27	0.296	0.09	0.107	0.469	0.041	0.261	0.028	0.324	0.003	0.130	0.001	0.414	0.103	0.34	0.006
2EC009	22	181.0	0.45	29.00	0.29	0.269	0.15	0.073	0.219	0.005	0.097	0.003	0.231	0.004	0.092	0.003	0.151	0.000	0.06	0.131
2EC011	16	282.0	0.46	55.25	0.25	0.315	0.12	0.089	0.421	0.029	0.211	0.008	0.332	0.007	0.133	0.000	0.249	0.017	0.46	0.001
2EC012	13	324.0	0.50	32.50	0.36	0.204	0.28	0.019	0.320	0.002	0.161	0.014	0.374	0.000	0.150	0.017	0.349	0.005	0.27	0.023
2EC101	12	24.3	0.82	32.00	0.25	0.315	0.18	0.057	1.018	0.590	0.621	0.195	0.074	0.031	0.030	0.023	0.064	0.014	0.03	0.149
2ED003	34	1180.0	0.55	61.75	2.26	2.099	1.45	1.063	0.837	2.024	0.493	0.915	1.230	1.061	0.492	0.918	1.554	0.011	3.10	7.190
2ED005	19	295.0	0.61	50.50	0.97	0.025	0.57	0.023	0.648	0.104	0.365	0.042	0.345	0.391	0.138	0.187	0.474	0.009	0.75	0.107
2ED007	17	177.0	0.63	28.00	0.96	0.022	0.78	0.130	0.539	0.177	0.308	0.223	0.227	0.537	0.091	0.475	0.301	0.229	0.26	0.024
2ED009	11	94.8	0.33	15.50	0.03	0.610	0.01	0.167	0.012	0.000	-0.035	0.002	0.145	0.013	0.058	0.002	0.025	0.000	0.11	0.095
2ED011	14	168.0	0.65	14.00	0.46	0.121	0.22	0.041	0.533	0.005	0.308	0.008	0.218	0.060	0.087	0.017	0.302	0.007	0.57	0.024
2ED100	14	86.0	0.57	17.75	0.15	0.437	0.06	0.129	0.379	0.052	0.206	0.021	0.136	0.000	0.054	0.000	0.122	0.004	0.09	0.111
2ED103	14	195.0	0.71	37.50	0.88	0.005	0.70	0.079	0.770	0.012	0.455	0.060	0.245	0.403	0.098	0.362	0.407	0.086	0.31	0.011
2HB001	58	205.0	0.45	15.00	0.60	0.043	0.32	0.010	0.168	0.189	0.068	0.062	0.255	0.121	0.102	0.046	0.171	0.021	0.45	0.001
2HB005	24	95.6	0.53	16.50	0.23	0.338	0.06	0.129	0.302	0.005	0.156	0.009	0.146	0.007	0.058	0.000	0.117	0.003	0.06	0.126
2HB008	20	127.0	0.57	21.00	0.36	0.204	0.23	0.036	0.390	0.001	0.212	0.000	0.177	0.033	0.071	0.025	0.179	0.003	0.04	0.144
2HB011	19	235.0	0.64	30.00	0.45	0.130	0.33	0.008	0.571	0.015	0.328	0.000	0.285	0.027	0.114	0.047	0.411	0.007	0.08	0.117
2HB013	20	62.2	0.65	9.00	0.21	0.360	0.14	0.076	0.522	0.097	0.303	0.025	0.112	0.010	0.045	0.010	0.112	0.001	0.10	0.101
2HC005	35	88.1	0.40	18.00	0.16	0.424	0.06	0.130	0.104	0.003	0.025	0.001	0.138	0.000	0.055	0.000	0.053	0.000	0.24	0.033
2HC006	29	249.0	0.54	29.48	0.74	0.005	0.37	0.002	0.371	0.136	0.197	0.030	0.299	0.194	0.120	0.063	0.316	0.003	0.67	0.062
2HC012	25	169.0	0.60	24.57	0.48	0.110	0.31	0.012	0.462	0.000	0.259	0.003	0.219	0.068	0.088	0.049	0.263	0.002	0.26	0.025
2HC013	17	88.1	0.43	15.20	0.23	0.338	0.08	0.115	0.138	0.008	0.048	0.001	0.138	0.008	0.055	0.001	0.065	0.000	0.08	0.115
2HC017	19	63.2	0.26	20.30	0.05	0.586	0.00	0.173	-0.043	0.008	-0.072	0.006	0.113	0.005	0.045	0.002	-0.005	0.000	0.09	0.109
2HC018	24	106.0	0.46	21.50	0.10	0.500	0.04	0.142	0.202	0.010	0.088	0.002	0.156	0.003	0.062	0.000	0.094	0.003	0.24	0.034
2HC019	24	93.5	0.58	17.48	0.46	0.123	0.33	0.008	0.397	0.004	0.218	0.012	0.144	0.101	0.057	0.073	0.137	0.036	0.10	0.099
2HC022	26	186.0	0.37	28.05	0.14	0.453	0.07	0.123	0.105	0.001	0.022	0.002	0.236	0.010	0.094	0.001	0.084	0.000	0.13	0.085
2HC023	25	62.2	0.57	11.75	0.18	0.395	0.13	0.086	0.364	0.033	0.198	0.005	0.112	0.005	0.045	0.006	0.088	0.001	0.08	0.117
2HC024	25	316.0	0.49	37.50	1.39	0.332	1.16	0.552	0.332	1.112	0.167	0.991	0.366	1.042	0.146	1.031	0.325	0.700	0.39	0.001
2HC025	25	303.0	0.59	45.00	0.82	0.000	0.59	0.030	0.564	0.066	0.314	0.077	0.353	0.218	0.141	0.202	0.457	0.018	0.08	0.112
2HC028	23	77.7	0.34	17.50	0.09	0.522	0.05	0.140	0.029	0.004	-0.024	0.005	0.128	0.001	0.051	0.000	0.024	0.000	0.11	0.096
2HC029	23	130.0	0.43	20.00	0.42	0.155	0.26	0.026	0.152	0.071	0.056	0.040	0.180	0.057	0.072	0.034	0.096	0.026	0.23	0.037
2HC030	21	204.0	0.24	38.00	0.23	0.340	0.14	0.077	0.028	0.040	-0.034	0.031	0.254	0.001	0.102	0.002	-0.035	0.031	0.17	0.062
2HC031	18	148.0	0.23	24.00	0.01	0.644	0.00	0.176	-0.053	0.004	-0.081	0.006	0.198	0.036	0.079	0.006	-0.033	0.001	0.12	0.091
2HC032	21	94.8	0.44	21.00	0.07	0.548	0.05	0.135	0.170	0.010	0.068	0.000	0.145	0.005	0.058	0.000	0.075	0.001	0.18	0.055
2HC033	21	70.6	0.25	29.50	0.10	0.511	0.05	0.140	-0.013	0.012	-0.057	0.010	0.121	0.001	0.048	0.000	-0.009	0.003	0.05	0.137
2HC034	18	194.0	0.17	22.00	0.01	0.648	0.00	0.176	-0.100	0.011	-0.111	0.012	0.244	0.057	0.098	0.010	-0.099	0.010	0.03	0.152
2HD003	28	67.3	0.70	15.50	0.48	0.107	0.30	0.014	0.648	0.022	0.384	0.007	0.117	0.134	0.047	0.064	0.137	0.026	0.21	0.042
2HD006	28	82.9	0.59	22.00	0.50	0.095	0.35	0.004	0.432	0.005	0.240	0.013	0.133	0.137	0.053	0.090	0.125	0.052	0.24	0.034
2HD009	22	82.6	0.62	15.00	0.34	0.221	0.23	0.037	0.471	0.017	0.267	0.002	0.133	0.043	0.053	0.031	0.137	0.008	0.35	0.004
2HD010	22	64.8	0.62	17.50	0.32	0.245	0.20	0.050	0.478	0.026	0.271	0.006	0.115	0.040	0.046	0.022	0.107	0.008	0.29	0.017
2HD012	11	232.0	0.66	21.00	1.39	0.333	1.04	0.381	0.576	0.660	0.335	0.492	0.282	1.223	0.113	0.852	0.428	0.369	0.92	0.249
2HH002	15	326.0	0.65	30.00	0.70	0.012	0.18	0.059	0.595	0.011	0.344	0.028	0.376	0.106	0.150	0.001	0.586	0.167	0.54	0.014
2HJ001	25	110.0	0.40	18.50	0.08	0.541	0.03	0.155	0.106	0.001	0.026	0.000	0.160	0.007	0.064	0.002	0.066	0.002	0.14	0.080
2HJ003	20	282.0	0.62	28.50	0.16	0.429	0.02	0.157	0.523	0.134	0.297	0.075	0.332	0.031	0.133	0.012	0.466	0.197	0.18	0.058
2HK005	19	456.0	0.76	35.50	0.80	0.000	0.23	0.037	0.892	0.008	0.337	0.097	0.506	0.088	0.202	0.001	1.061	0.697	0.47	0.002
2HK006	14	541.0	0.62	60.00	0.16	0.428	0.02	0.158	0.772	0.378	0.439	0.175	0.591	0.188	0.236	0.046	0.895	0.763	0.26	0.027
2HL001	67	2620.0	0.71	87.00	1.477	0.443	0.582	0.027	3.514	4.149	2.366	3.183	2.670	1.423	1.068	0.236	5.466	23.856	1.15	0.541
2HL003	18	401.0	0.60	66.50	0.450	0.130	0.061	0.128	0.788	0.115	0.442	0.145	0.451	0.000	0.180	0.014	0.625	0.318	0.03	0.149
2HM002	30	189.0	0.65	20.00	0.322	0.239	0.039	0.144	0.550	0.052	0.318	0.078	0.239	0.007	0.096	0.003	0.340	0.090	0.06	0.129
2HM003	24	891.0	0.77	112.40	0.145	0.444	0.034	0.148	1.943	3.232	1.140	1.223	0.941	0.634	0.376	0.117	2.116	4.335	0.12	0.087
2HM005	10	155.0	0.49	27.00	0.025	0.618	0.000	0.176	0.272	0.061	0.132	0.018	0.205	0.032	0.082	0.007	0.159	0.025	0.03	0.153
2HM006	13	150.0	0.63	40.00	0.095	0.513	0.039	0.144	0.607	0.262	0.346	0.094	0.200	0.011	0.080	0.002	0.255	0.047	0.00	0.172
2HM007	10	694.0	0.78	50.50	1.159	0.121	0.355	0.004	1.080	0.006	0.653	0.089	0.744	0.172	0.298	0.003	1.682	1.760	0.09	0.111
2KA003	20	7.0	0.50	3.00	0.001	0.656	0.000	0.176	0.230	0.052	0.110	0.012	0.057	0.003	0.023	0.001	0.008	0.000	0.00	0.176
2KB001	67	4120.0	0.88	107.60	11.292	109.847	6.560	37.711	10.742	0.303	7.542	0.964	4.170	50.723	1.668	23.932	11.963	29.194	1.00	0.332
2KC009	61	2380.0	0.68	90.00	4.762	15.609	2.830	5.813	2.930	3.355	1.938	0.795	2.430	5.438	0.972	3.452	4.622	3.212	4.02	12.994
2KF011	12	269.0	0.33	35.00	0.059	0.566	0.010	0.167	0.097	0.001	0.013	0.000	0.319	0.068	0.128	0.014	0.070	0.004	0.88	0.208
2KF012	11 .	203.0	0.61	37.50	0.278	0.284	0.181	0.057	0.550	0.074	0.310	0.017	0.253	0.001	0.101	0.006	0.326	0.021	0.26	0.027
2KF013	11	280.0	0.67	32.50	0.150	0.437	0.021	0.158	0.651	0.251	0.379	0.128	0.330	0.032	0.132	0.012	0.530	0.259	0.01	0.164
2KF014	12	277.0	0.59	53.00	0.109	0.493	0.000	0.176	0.629	0.270	0.350	0.123	0.327	0.048	0.131	0.017	0.418	0.175	0.11	0.094
2LA004	34	3830.0	0.52	92.50	5.705	23.949	3.118	7.284	7.943	5.007	5.604	6.181	3.880	3.331	1.552	2.452	4.492	1.888	10.82	108.130
2LA006	13	409.0	0.41	63.00	0.076	0.541	0.008	0.169	0.431	0.126	0.210	0.041	0.459	0.147	0.184	0.031	0.263	0.065	0.00	0.176
2LA007	14	559.0	0.38	60.50	0.086	0.526	0.012	0.166	0.378	0.086	0.180	0.028	0.609	0.274	0.244	0.054	0.279	0.072	1.51	1.199
2LB006	35	433.0	0.30	36.30	0.195	0.380	0.089	0.109	0.080	0.013	0.002	0.008	0.483	0.083	0.193	0.011	0.050	0.002	0.01	0.167
2LB008	25	440.0	0.30	46.20	0.161	0.423	0.105	0.099	0.149	0.000	0.040	0.004	0.490	0.108	0.196	0.008	0.051	0.003	0.02	0.162
2LB017	9	69.0	0.30	15.00	0.329	0.080	0.097	0.104	-0.021	0.302	-0.056	0.024	0.119	0.168	0.048	0.002	0.008	0.008	0.00	0.175
2LB022	9	152.0	0.30	34.00	0.027	0.615	0.001	0.175	0.057	0.001	-0.013	0.000	0.202	0.031	0.081	0.006	0.018	0.000	0.02	0.161
2MC001	26	404.0	0.37	26.00	0.044	0.589	0.004	0.172	0.103	0.004	0.022	0.000	0.454	0.168	0.182	0.032	0.183	0.032	0.01	0.168
				AVG	0.811	2.919	0.419	0.881	0.763	0.720	0.468	0.262	0.482	1.386	0.193	0.538	0.722	1.057	0.534	2.018
				STD	1.709	13.585	0.939	4.600	1.611	2.373	1.137	0.850	0.759	6.436	0.303	2.889	1.733	4.500	1.416	12.991
				SUM	55.972	201.425	28.915	60.805	52.636	49.707	32.270	18.109	33.259	95.603	13.303	37.142	49.815	72.958	36.867	139.219
				N.S.R^2					0.75		0.70		0.53		0.39		-0.20		-1.29	

Qy is the n day low flows with y years of recurrence interval.

-Estimated by Regression Method, I-Index, B-Baseflow isolines and U-Mapping Procedure.

APPENDIX F

SIMPLE CORRELATION OF PARAMETERS

The following Table F.1 is a matrix of the correlation coefficients for the untransformed independent parameters used in this study.

TABLE F.1

SIMPLE CORRELATION OF PARAMETERS

CENTRAL REGION

CORRELATIONS /VARIABLES GW TO Q20.

SPSS/PC+

Correlations:	GW	RN	MAP	MAS	MAR	SLP	EVA	DA	BFI	LNTH	ACLS	Q2	Q20
GW	1.0000	.1252	.2186	-.0308	.0268	-.0969	-.1395	.0466	.0814	-.0891	.0592	.0850	.0277
RN	.1252	1.0000	-.0220	-.1908	.0135	-.2146	.1062	-.1160	.0545	-.1264	.1633	-.1835	-.3117
MAP	.2186	-.0220	1.0000	.6877**	.4419**	-.3717*	-.8926**	.5100**	.4852**	.3401*	.3665*	.6106**	.4746**
MAS	-.0308	-.1908	.6877**	1.0000	.1567	-.4484**	-.6268**	.5407**	.3408*	.5200**	.3368*	.4611**	.4696**
MAR	.0268	.0135	.4419**	.1567	1.0000	.0512	-.5550**	.2805	.6374**	.2248	.0800	.4637**	.4274*
SLP	-.0969	-.2146	-.3717*	-.4484**	.0512	1.0000	.3273	-.3831*	-.0691	-.3918*	-.4257*	-.1544	-.0650
EVA	-.1395	.1062	-.8926**	-.6268**	-.5550**	.3273	1.0000	-.5488**	-.4850**	-.3664*	-.4186*	-.7106**	-.4974**
DA	.0466	-.1160	.5100**	.5407**	.2805	-.3831*	-.5488**	1.0000	.3395*	.8130**	.3606*	.7147**	.6621**
BFI	.0814	.0545	.4852**	.3408*	.6374**	-.0691	-.4850**	.3395*	1.0000	.2485	.2207	.4465**	.4569**
LNTH	-.0891	-.1264	.3401*	.5200**	.2248	-.3918*	-.3664*	.8130**	.2485	1.0000	.2610	.4453**	.4743**
ACLS	.0592	.1633	.3665*	.3368*	.0800	-.4257*	-.4186*	.3606*	.2207	.2610	1.0000	.2697	.1313
Q2	.0850	-.1835	.6106**	.4611**	.4637**	-.1544	-.7106**	.7147**	.4465**	.4453**	.2697	1.0000	.8825**
Q20	.0277	-.3117	.4746**	.4696**	.4274*	-.0650	-.4974**	.6621**	.4569**	.4743**	.1313	.8825**	1.0000

N of cases: 48 1-tailed Signif: * - .01 ** - .001

" . " is printed if a coefficient cannot be computed

SOUTHEASTERN REGION

CORRELATIONS /VARIABLES GW TO Q20.

SPSS/PC+

Correlations:	GW	RN	MAP	MAS	MAR	SLP	EVA	DA	BFI	LNTH	ACLS	Q2	Q20
GW	1.0000	.2097	..5615*	-.5442*	.3537	-.0007	.6546**	-.1956	.2783	.0127	.4295	-.2543	-.2756
RN	.2097	1.0000	.2034	-.4268	-.1866	-.0598	.2629	.3512	.7458**	.4444	.7734**	.2999	.2782
MAP	.5615*	.2034	1.0000	-.6399**	.4068	.0913	.4785*	-.3045	.2731	-.2364	.3149	-.2837	-.2992
MAS	-.5442*	-.4268	-.6399**	1.0000	-.1315	-.1028	-.5093*	.0352	-.3977	-.0779	-.5001*	.1174	.1388
MAR	.3537	-.1866	.4068	-.1315	1.0000	-.5544*	.5277*	-.3392	-.1879	-.2272	-.0578	-.2710	-.2664
SLP	-.0007	-.0598	.0913	-.1028	-.5544*	1.0000	-.4810*	-.1345	.1219	-.3049	.1475	-.0573	-.0491
EVA	.6546**	.2629	.4785*	-.5093*	.5277*	-.4810*	1.0000	-.2760	-.0026	-.0366	.2452	-.4564	-.4842*
DA	-.1956	.3512	-.3045	.0352	-.3392	-.1345	-.2760	1.0000	.4455	.7739**	.0739	.9007**	.8877**
BFI	.2783	.7458**	.2731	-.3977	-.1879	.1219	-.0026	.4455	1.0000	.5122*	.6429**	.4568	.4325
LNTH	.0127	.4444	-.2364	-.0779	-.2272	-.3049	-.0366	.7739**	.5122*	1.0000	.2047	.6302**	.6218**
ACLS	.4295	.7734**	.3149	-.5001*	-.0578	.1475	.2452	.0739	.6429**	.2047	1.0000	.0990	.0781
Q2	-.2543	.2999	-.2837	.1174	-.2710	-.0573	-.4564	.9007**	.4568	.6302**	.0990	1.0000	.9976**
Q20	-.2756	.2782	-.2992	.1388	-.2664	-.0491	-.4842*	.8877**	.4325	.6218**	.0781	.9976**	1.0000

N of cases: 25 1-tailed Signif: * - .01 ** - .001

" . " is printed if a coefficient cannot be computed

COMBINED REGIONS

CORRELATIONS /VARIABLES GW TO Q20.

SPSS/PC+

Correlations:	GW	RN	MAP	MAS	MAR	SLP	EVA	DA	BFI	LNTH	ACLS	Q2	Q20
GW	1.0000	.1537	.2859*	-.0424	.2430	-.1772	-.0324	.0288	.1768	.1740	.3757**	-.0957	-.1381
RN	.1537	1.0000	.0334	-.1893	-.0224	-.1601	.1142	.1578	.3121*	.1448	.3703**	.0877	.0673
MAP	.2859*	.0334	1.0000	.5790**	.4322**	-.2413	-.4622**	.0647	.4135**	.1197	.3370*	.1616	.0402
MAS	-.0424	-.1893	.5790**	1.0000	.1505	-.3596**	-.4924**	.2133	.2181	.3059*	.2258	.2371	.1892
MAR	.2430	-.0224	.4322**	.1505	1.0000	-.1845	-.3709**	.0630	.3890**	.1570	.1352	.1426	.0685
SLP	-.1772	-.1601	-.2413	-.3596**	-.1845	1.0000	.1917	-.2765*	.0010	-.4229**	-.2902*	-.1271	-.0859
EVA	-.0324	.1142	-.4622**	-.4924**	-.3709**	.1917	1.0000	-.4366**	-.2571	-.3745**	-.3256*	-.4953**	-.4130**
DA	.0288	.1578	.0647	.2133	.0630	-.2765*	-.4366**	1.0000	.3463*	.7858**	.2481	.8507**	.8453**
BFI	.1768	.3121*	.4135**	.2181	.3890**	.0010	-.2571	.3463*	1.0000	.3535*	.3725**	.4180**	.3811**
LNTH	.1740	.1448	.1197	.3059*	.1570	-.4229**	-.3745**	.7858**	.3535*	1.0000	.3360*	.5721**	.5643**
ACLS	.3757**	.3703**	.3370*	.2258	.1352	-.2902*	-.3256*	.2481	.3725**	.3360*	1.0000	.1906	.1213
Q2	-.0957	.0877	.1616	.2371	.1426	-.1271	-.4953**	.8507**	.4180**	.5721**	.1906	1.0000	.9709**
Q20	-.1381	.0673	.0402	.1892	.0685	-.0859	-.4130**	.8453**	.3811**	.5643**	.1213	.9709**	1.0000

N of cases: 73 1-tailed Signif: * - .01 ** - .001

" . " is printed if a coefficient cannot be computed

FIGURE 3.1

Cumming Cockburn Limited
Consulting Engineers and Planners

PERCY

10.60 | 15.00

SOUTHEASTERN ONTARIO

LOW FLOW CHARACTERISTICS OF STREAMS IN CENTRAL ONTARIO

Ministry of the Environment
Water Resources Branch

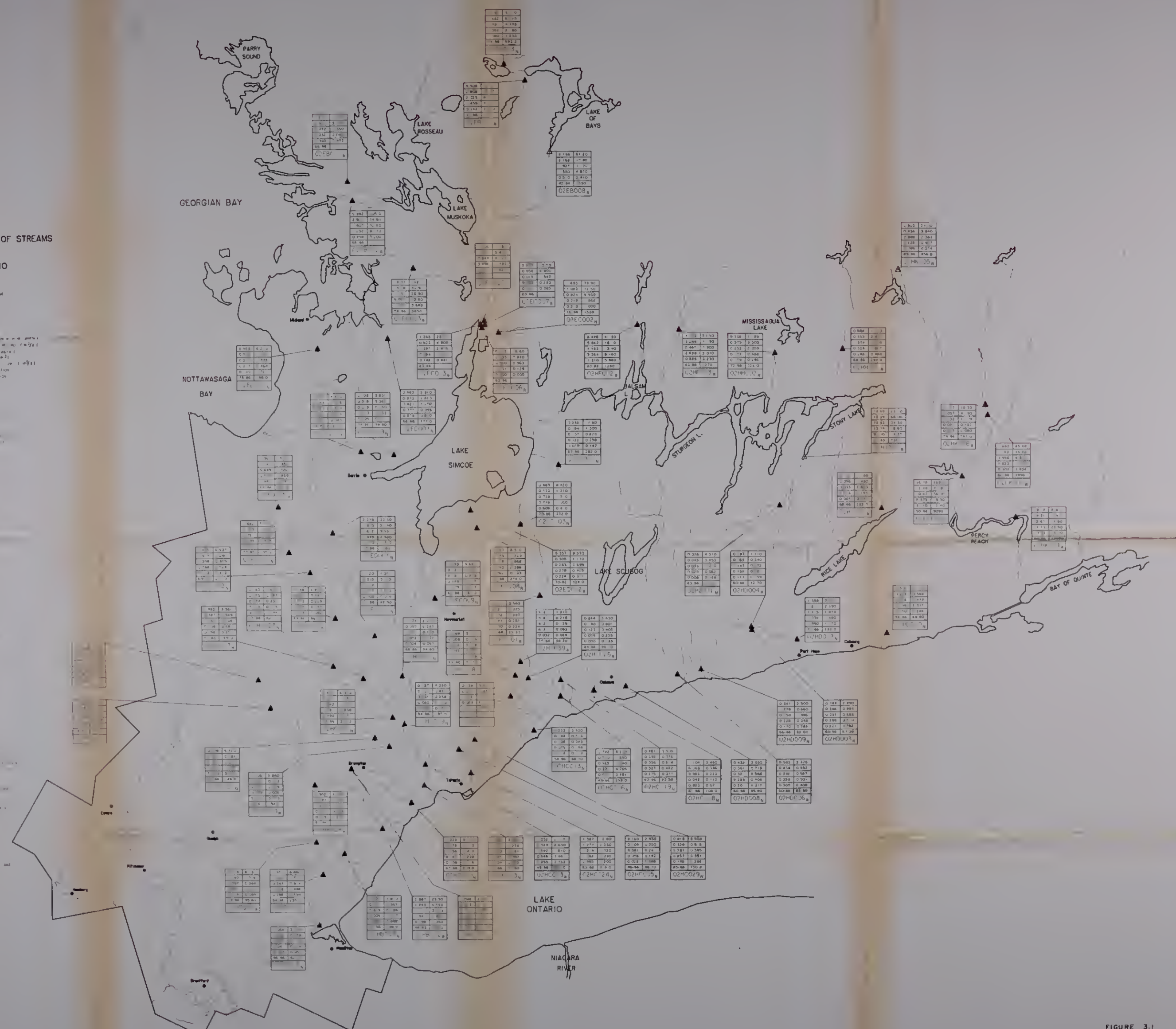


FIGURE 3.1

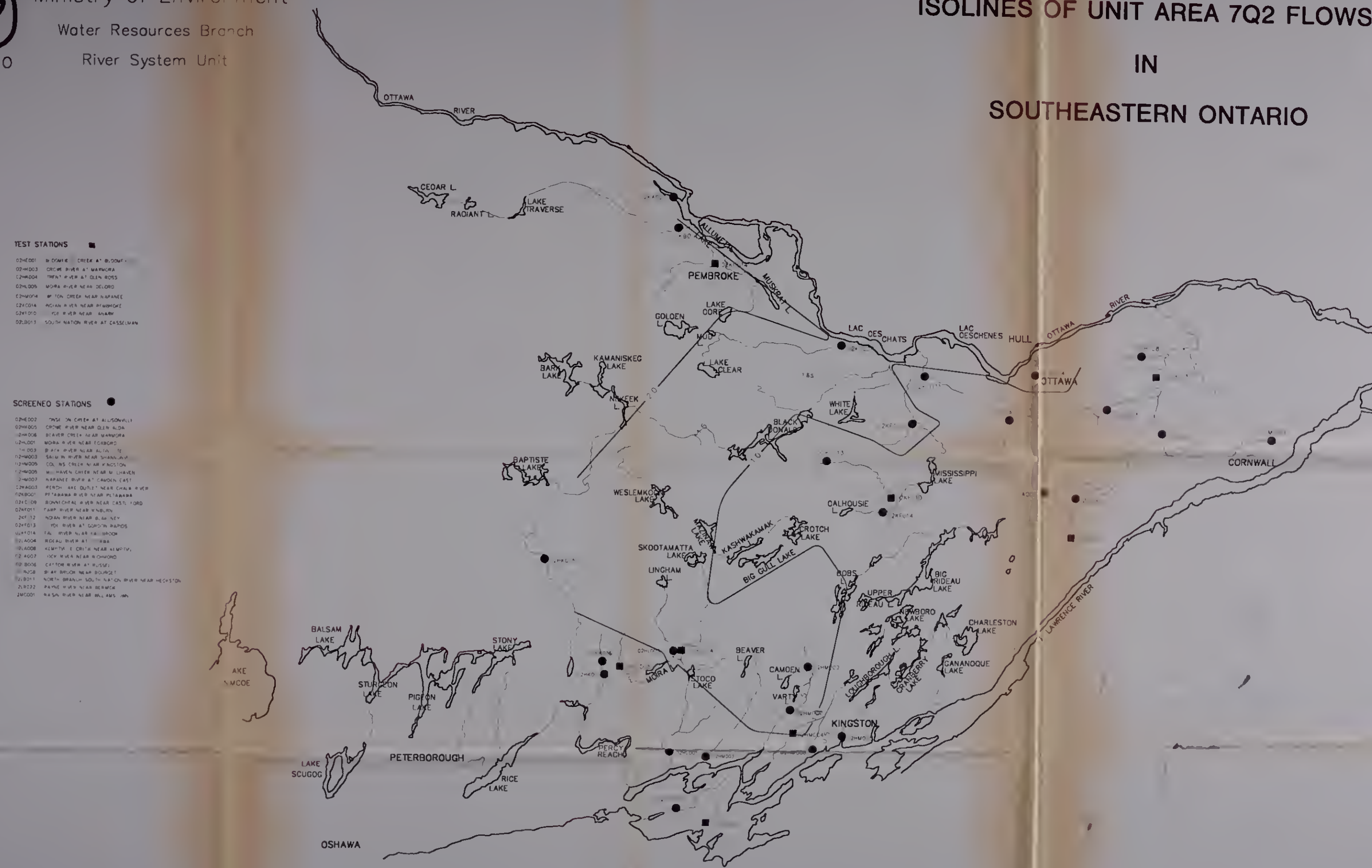
Cumming Cockburn Limited
Consulting Engineers and Planners

LOW-FLOW CHARACTERISTICS OF STREAMS
IN
SOUTHEASTERN ONTARIO

Ministry of Environment
Water Resources Branch
River System Unit

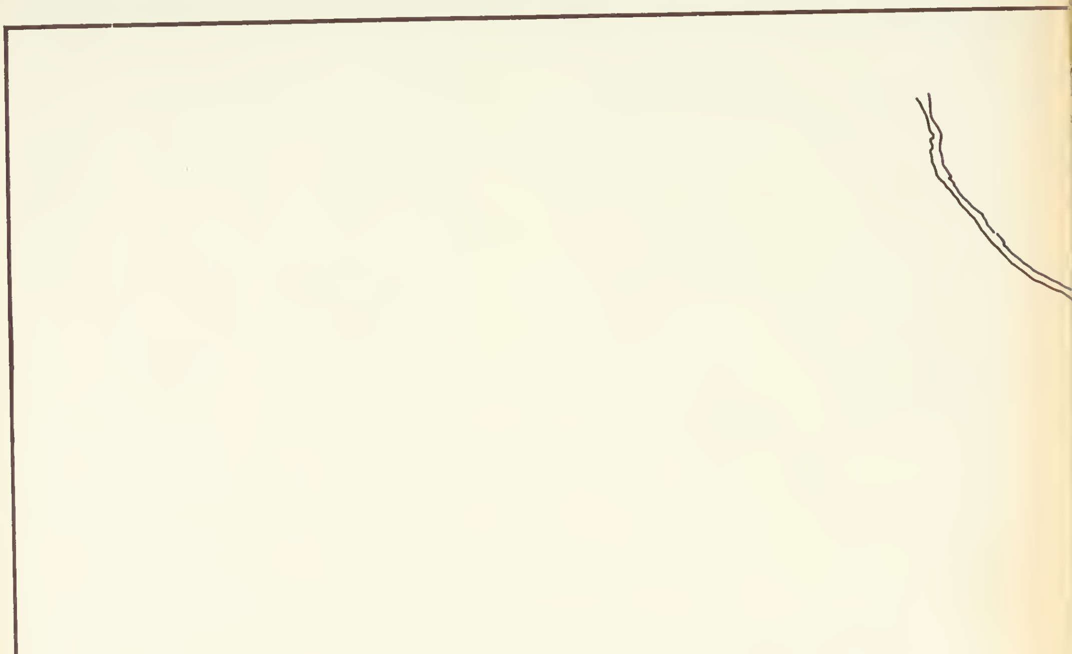
ONTARIO

ISOLINES OF UNIT AREA 7Q2 FLOWS IN SOUTHEASTERN ONTARIO



Cumming Cockburn Limited
Consulting Engineers, Planners & Environmental Scientists

Figure 5.3 (b)



LOW-FLOW CHARACTERISTICS OF STREAMS
IN
SOUTHEASTERN ONTARIO

ISOLINES OF UNIT AREA 7Q2 FLOWS IN CENTRAL AND SOUTHEASTERN ONTARIO

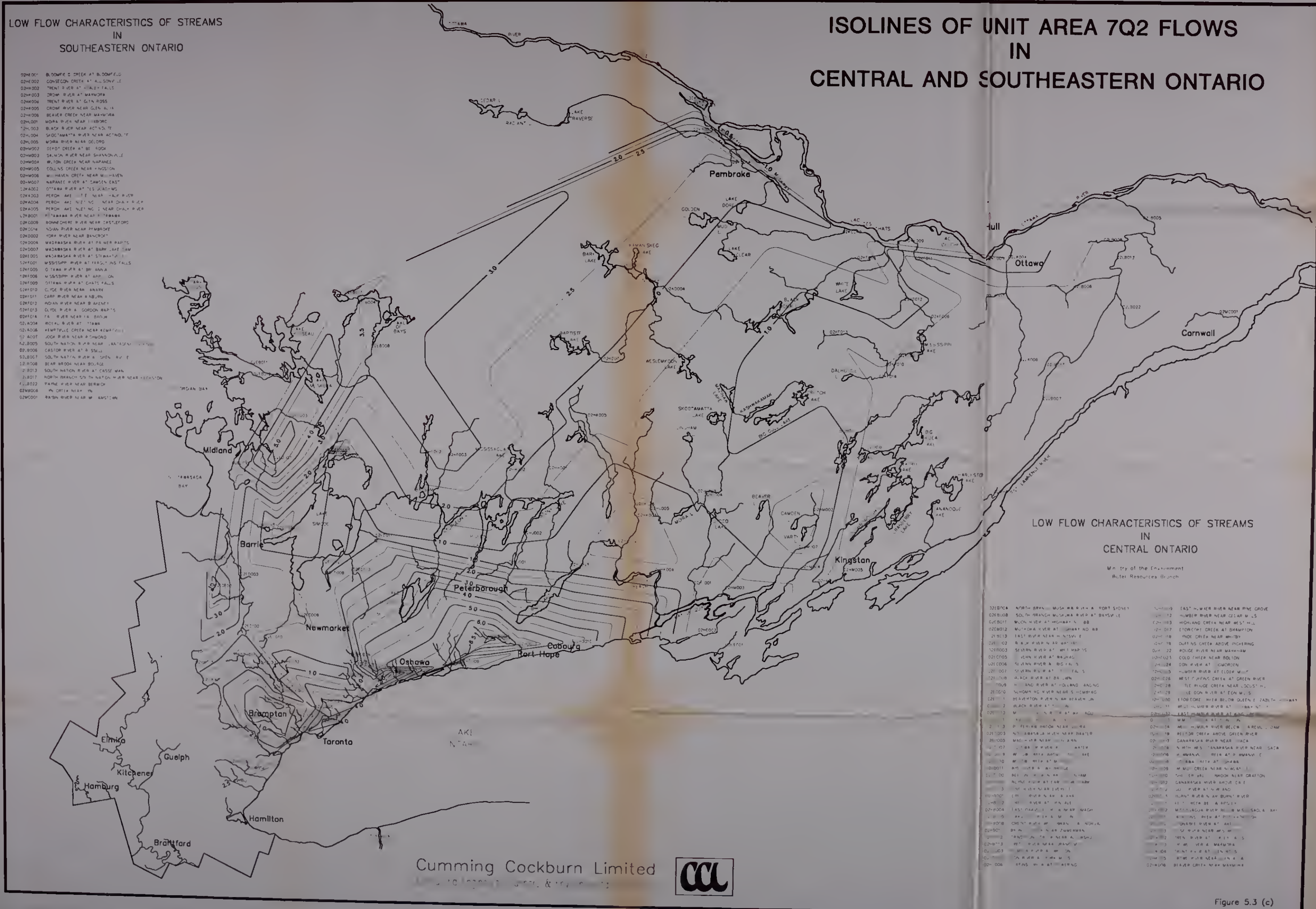


Figure 5.3 (c)

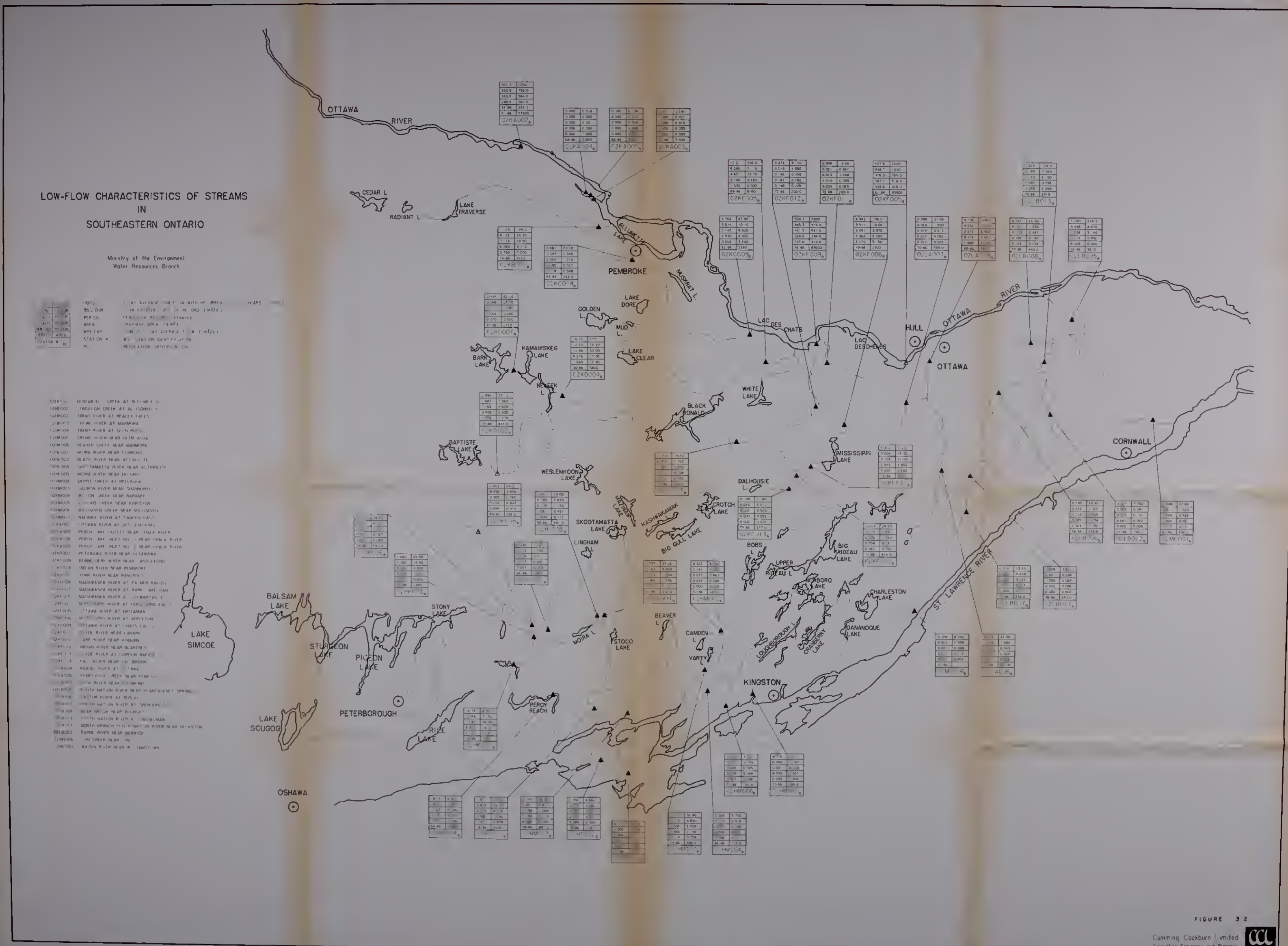

LOW-FLOW CHARACTERISTICS OF STREAMS
IN
SOUTHEASTERN ONTARIO
Ministry of the Environment
Water Resources Branch
OTTAWA RIVER
CEDAR L.
RADIANT L.
LAKE TRAVERSE
PEMBROKE
ALLUMETTE LAKE
MUSKRAT L.
GOLDEN L.
LAKE DORE
MUD L.
LAKE CLEAR
KAMANISKEG LAKE
BARK LAKE
BAPTISTE LAKE
WESLEMKOON LAKE
BLACK DONALD
WHITE LAKE
LAC DES CHATS
LAC DESCHENES
HULL
OTTAWA
MISSISSIPPI LAKE
DALHOUSIE L.
CROTCH LAKE
SKOOTAMATTA LAKE
KASHWAKAMAK
BIG GULL LAKE
LINGHAM
BOBS L.
UPPER RIDEAU L.
BIG RIDEAU LAKE
NEWBORO LAKE
CHARLESTON LAKE
GANANOQUE LAKE
LOUGHBOROUGH L.
CHARLESTON LAKE
BEAVER L.
CAMDEN L.
VARTY L.
STOCO LAKE
MOIRA L.
KINGSTON
CORNWALL
ST. LAWRENCE RIVER
BALSAM LAKE
LAKE SIMCOE
STURGEON LAKE
STONY LAKE
PIGEON LAKE
PETERBOROUGH
RICE LAKE
PERCY REACH
LAKE SCUGOG
OSHAWA
02KA002
02KC009
02KF012
02KF005
02KF009
02KF006
02KD004
02KD007
FIGURE 3.2
Cumming Cockburn Limited
Consulting Engineers and Planners

Figure 5.3 (a)

ISOLINES OF UNIT AREA 7Q20 FLOWS IN CENTRAL AND SOUTHEASTERN ONTARIO

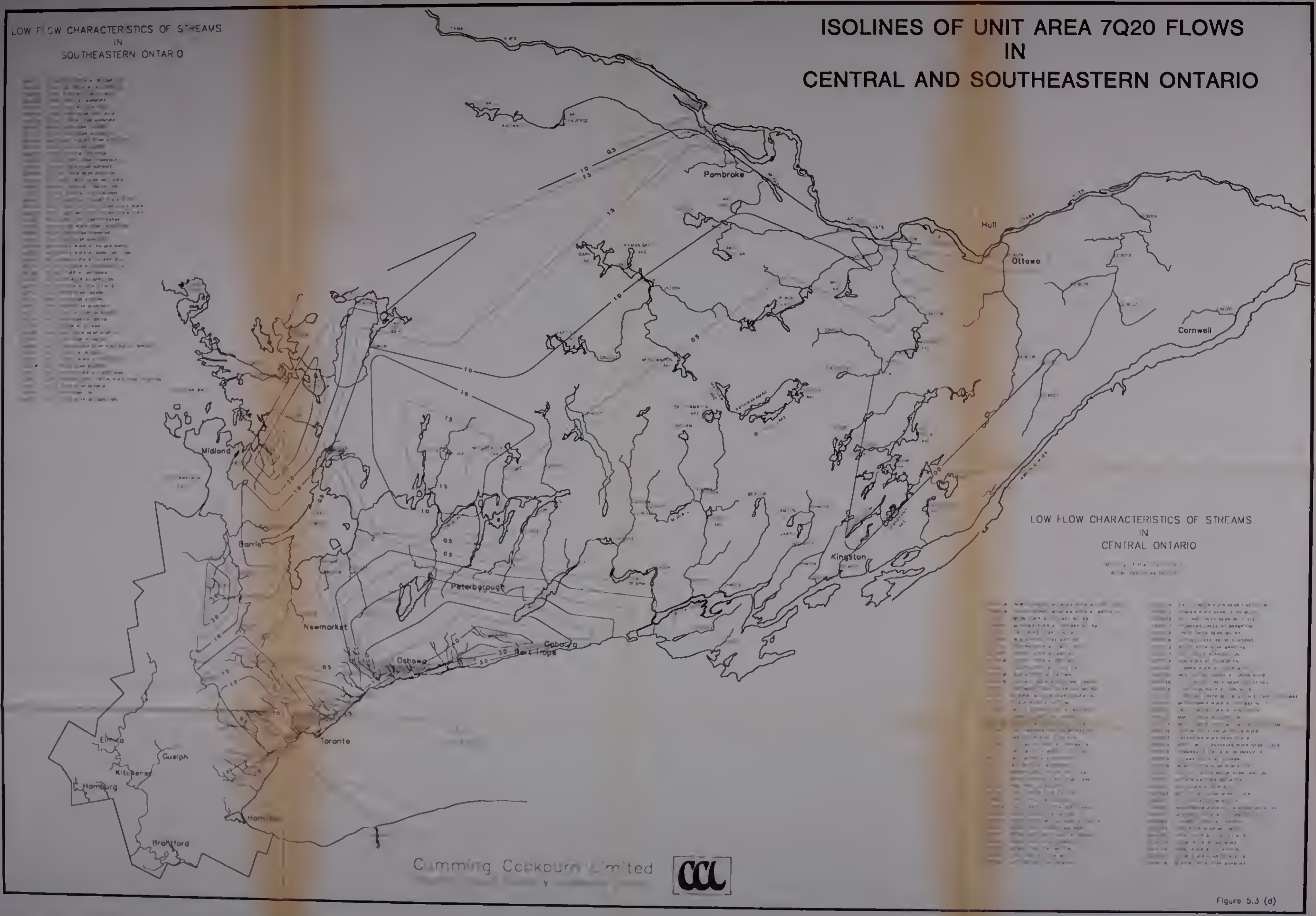
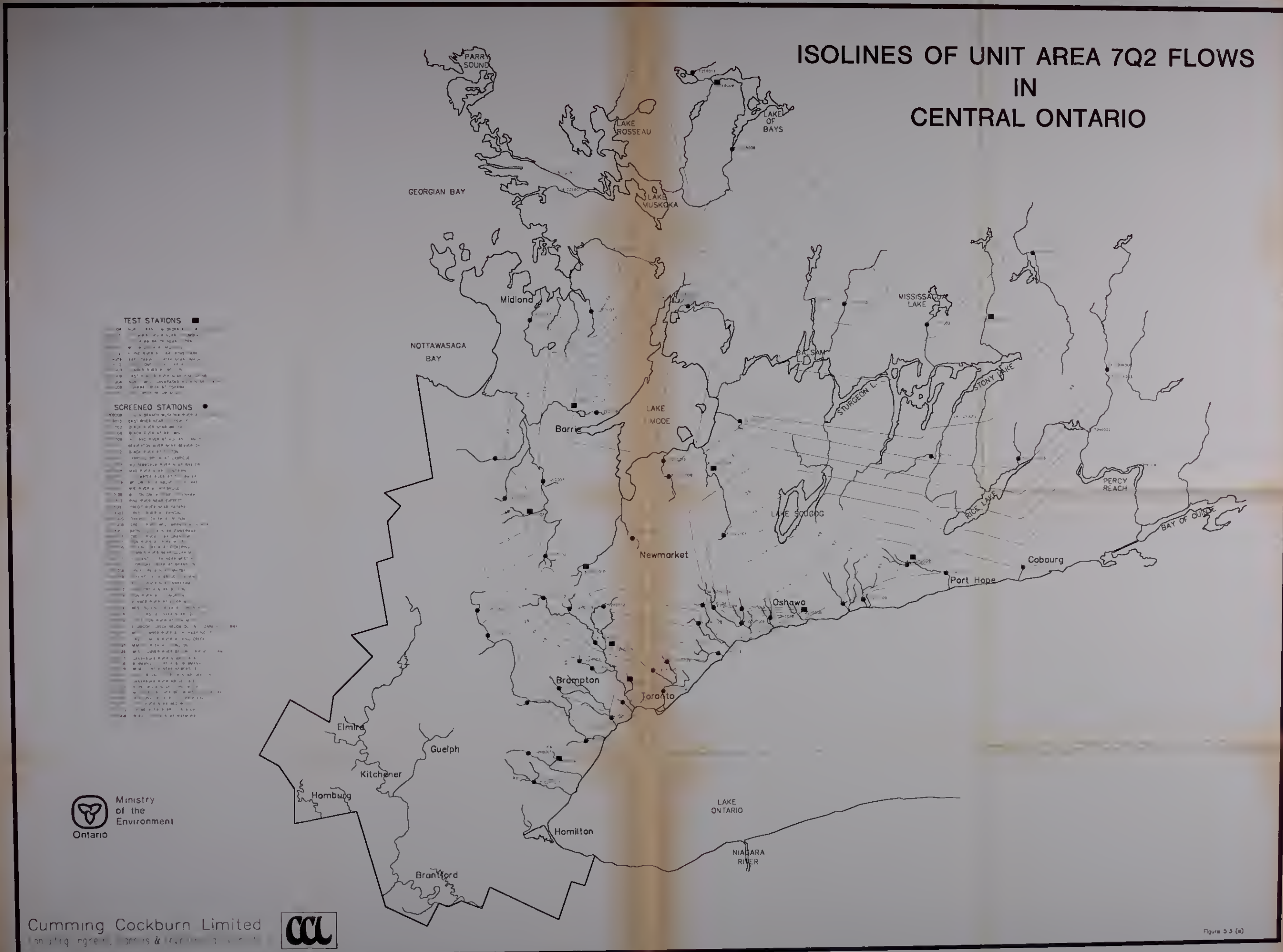


Figure 5.3 (d)

Figure 5.3 (a)



ISOLINES OF UNIT AREA 7Q2 FLOWS IN CENTRAL ONTARIO
PARRY SOUND
LAKE ROSSEAU
LAKE OF BAYS
GEORGIAN BAY
LAKE MUSKOKA
Midland
NOTTAWASAGA BAY
TEST STATIONS
SCREENED STATIONS
MISSISSAGUA LAKE
BALSAM
STURGEON L.
STONY LAKE
LAKE SIMCOE
Barrie
LAKE SCUGOG
RICE LAKE
PERCY REACH
BAY OF QUINTE
Newmarket
Cobourg
Port Hope
Oshawa
Brampton
Toronto
Elmira
Guelph
Kitchener
Homburg
Hamilton
LAKE ONTARIO
NIAGARA RIVER
Brantford
Ministry of the Environment
Ontario
Cumming Cockburn Limited
CCL
Figure 5.3 (a)